Florida Water Resources Research Center
Annual Technical Report
FY 2014

Introduction

The mission of the Florida Water Resources Research Center at the University of Florida is to facilitate communication and collaboration between Florida's Universities and the state agencies that are responsible for managing Florida's water resources. A primary component of this collaborative effort is the development of graduate training opportunities in critical areas of water resources that are targeted to meet Florida's short- and long-term needs.

The Florida Water Resources Research Center coordinates graduate student funding that is available to the state of Florida under the provisions of section 104 of the Water Resources Research Act of 1984. Over the past year (Fiscal Year 2014) the Center supported multiple research projects including agreements with two of Florida s universities (Florida Atlantic University and the University of Florida), two state agencies (South Florida Water Management District, St. Johns River Water Management District) and one municipality (City of Sanford).

Recognizing the importance of STEM (Science, Technology, Engineering, and Mathematics) Education initiatives, the Florida Water Resources Research Center is very proud to have supported the research efforts of **8 Ph.D., 3 Master's, and 2 Bachelor's students along with one Post-Doctoral researcher** all focusing on water resources issues during the reporting period (March 2014 to February 2015).

During FY 2014, along with providing support to graduate students within the state of Florida, the Center also facilitated development of research at both the state and national level producing **19 peer-reviewed journal articles, 2 book chapters, 7 proceedings and presentations, 3 Ph.D. Dissertations, 2 Master s Thesis, and 1 US Patent.** The Center is a state repository for water resources related publications and maintains a library of technical reports that have been published as a result of past research efforts (Dating back to 1966). Several of these publications are widely used resources for water policy and applied water resources research in the state of Florida and are frequently requested by others within the United States. As part of the WRRC information and technology transfer mission, the library was converted to digital form and is provided free to the public through the WRRC Digital Library available on the center website (http://wrrc.essie.ufl.edu/).

Research Program Introduction

During FY 2014 the Water Resources Research Center supported four 104B research projects and four center-affiliated research projects. The supported research projects considered a wide range of water resource related issues while maintaining focus on topics relevant to Florida and the nation.

104B Research Projects

Watershed Management in the face of EPA's New Numeric Nutrient Criteria for Florida Waters. In January 2010 the US Environmental Protection Agency embarked on a new approach to regulate nutrient pollution in aquatic ecosystems. Previously, nutrients were managed according to narrative criteria that categorized water bodies as impaired using observed biological responses, specifically an imbalance in the native flora and fauna of the aquatic ecosystem. Now, rather than waiting for biological impairment to become apparent before implementing ecologically protective nutrient levels, EPA will regulate nutrients according to now finalized numeric criteria (http://water.epa.gov/lawsregs/rulesregs/upload/floridaprepub.pdf). Under this plan, concentration thresholds will be established for each water body type (i.e., lakes, wetlands, rivers/streams, springs, estuaries, and canals) and enforced uniformly statewide.

The overall goal of this project is to fund an interdisciplinary cohort of 6 Ph. D. Fellows to develop the new knowledge, and creative engineering, management and policy solutions needed to establish and achieve numeric nutrient criteria (NNC) for Florida's waters. The education and research of each Fellow will evolve from specific problems and research questions related to management of Florida's water and watersheds under NNC. The unique cross-disciplinary environment of our program will allow an integrated whole that will reflect disciplinary facets associated with this complex problem.

Sustainable Urban Infrastructure and Water Loss Management Including a Case Study of Sanford Florida. Continued growth in water demand in many parts of the country including Florida has placed significant stress on traditional groundwater and surface water sources for urban water supply. Regional water supply assessments by the water management districts have shown significant negative impacts of these developments including lowered groundwater tables accompanied by reduced flows in rivers and springs, declining lake levels, and increasing nutrient loads on receiving waters. In response to these problems, water utilities are required to evaluate alternative water supplies and water conservation to meet future water needs. Water reuse for irrigation represents the largest potential for water conservation in areas where outdoor water use is significant as it is in Florida. The EZ Guide 2.0 model will be refined to address these needs to find cost-effective solutions. EZ Guide 2.0 has been developed by the Conserve Florida Water Clearinghouse to find the optimal portfolio of traditional and alternative water supply options and demand management.

Development of a Passive Sensor for Measuring Water and Contaminant Fluxes in the Hyporheic Zone. The goal of this student lead seed project is to develop a new passive technology that will incorporate the field-tested concepts of the passive flux meter (PFM) to provide direct in situ measurements of water and contaminant fluxes within the hyporheic zone. The proposed effort will develop a new sensor, test it under controlled laboratory conditions and develop field deployment strategies. If a robust technology is developed from this seed project, follow on proposals will be generated to pursue additional funding to support further development of the novel technology. The new technology will improve the ability of site managers to formulate a site-wide contaminant mass balance, evaluate the efficacy of hyporheic zone for monitored natural attenuation, manage aquatic sediment site restoration, control private and public expectations of restoration efforts, and ensure protection of human health and the environment.

Development and Evaluation of Data Accuracy Assessment Algorithms for Identifying Anomalies in Hydro-meteorological Data (Phase II). Acquisition of hydrologic and hydraulic data is the key component of water resources management in central and south Florida. The South Florida Water Management District (SFWMD) is responsible for the collection, validation, and archiving of the District's hydrologic data. The types of data include rainfall, evaporation, water levels (stage), water control structure (gate and pump) operations, and flow. The District requires accurate data collection, processing and archiving of these data. There is a constant need for good quality hydrometerologic data for operations of large canal network. In early 2013, the Hydro Data Management (HDM) at SFWMD initiated an effort to review and evaluate different data accuracy assessment algorithms for development of a prototype tool for identifying the anomalies in stage data. In the completed first phase of study a prototype tool, Hydrologic Data Evaluation Tool (HDET) was developed. The second phase of this continuing project built on the prior work from phase I and worked towards several improvements and testing of the HDET.

Sustainable Urban Infrastructure and Water Loss Management Including a Case Study of Sanford Florida

Basic Information

Title:	Sustainable Urban Infrastructure and Water Loss Management Including a Case Study of Sanford Florida
Project Number:	2011FL269B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	3
Research Category:	Engineering
Focus Category:	Water Supply, Management and Planning, Models
Descriptors:	None
Principal Investigators:	James Heaney

Publications

1. Heaney, J. and J. Sansalone. 2012. A Vision for Urban Stormwater Management in 2050. Chapter 17 in Grayman, W. Loucks, D. and L. Saito, Eds. Toward a Sustainable Water Future: Vision for 2050, ASCE Press, Reston, VA.
2. Heaney, J., Friedman, K., and M. Morales. 2011. International Perspective on Urban Water Conservation. Proc. 8th Int. Conf. on Urban Watershed Man., Beijing, China, Sept.
3. Heaney, J., Switt, R., Friedman, K., Morales, M., and K. Riley. 2011. Overview of EZ Guide for Water Conservation Evaluations. Florida Water Resources Journal, September.
4. Friedman, K., Heaney, J., Morales, M. and J. Palenchar. 2011. Water Demand Management Optimization Methodology. Jour. American Water Works Assoc., Vol. 103, No. 9.
5. Morales, M., Heaney, J., Friedman, K., and Martin J. 2011. Estimating Commercial, Industrial, and Institutional Water Use on the Basis of Heated Building Area. Jour. American Water Works Assoc., Vol. 103, No. 6.
6. Morales, M., and J. Heaney. 2010. Predominant Commercial Sectors in Florida and their Water Use Patterns. Florida Water Resources Journal, August.
7. Friedman, K. and J. Heaney. 2009. Water Loss Management: Conservation Option in Florida s Urban Water Systems. Florida Water Resources Journal, August, p 24-32. http://www.fwrj.com/techarticles/0809%20FWRJ%20tech1.pdf.
8. Friedman, K. and J. Heaney. 2009.Validity of Water Audit and Water Loss Evaluations for Florida. Proc. Florida Section of AWWA Fall Conference, Orlando, December.
9. Morales, M., Heaney, J., Friedman, K. and J. Martin .2013. Parcel-level model of water and energy end use. Jour. American Water Works Assn., accepted for publication.
10. Friedman, K., Heaney, J. Morales, M. and J. Palenchar. 2013. Predicting and Managing Residential Potable Irrigation Using Parcel Level Databases. Jour. American Water Works Assn., accepted for publication.
11. Morales, M, Martin, J., Heaney, J. and K. Friedman. 2013. Parcel Level Modeling of Seven End Use Water Demands in 64 Public Supply Land Use Sectors. Jour. American Water Works Assn., accepted for publication.

12. Heaney, J., Switt, R., Friedman, K., Morales, M., and K. Riley. 2011. Overview of EZ Guide for Water Conservation Evaluations. Florida Water Res. Jour., Sept.
13. Heaney, J. and J. Sansalone. 2012. A Vision for Urban Stormwater Management in 2050. Chapter 17 in Grayman, W. Loucks, D. and L. Saito, Eds. Toward a Sustainable Water Future: Vision for 2050, ASCE Press, Reston, VA.
14. Friedman, K. 2013. Simulation/Optimization of Alternative Water Supply Planning Using Parcel Level Demand Estimation and Management Strategies.Ph.D. Dissertation, Dept. of Environmental Engineering Sciences, U. of Florida, Gainesville, FL.
15. Friedman, K., Heaney, J. Morales, M. and J. Palenchar. 2013. Predicting and Managing Residential Potable Irrigation Using Parcel Level Databases . Jour.American Water Works Assn., Vol. 105, No. 7.
16. Morales, M., Heaney, J., Friedman, K. and J. Martin .2013. Parcel-level model of water and energy end use. Jour . American Water Works Assn., Vol. 105, No. 8.
17. Morales, M, Martin, J ., Heaney, J. and K. Friedman. 2013. Parcel Level Modeling of Seven End Use Water Demands in 64 Public Supply Land Use Sectors. Jour. American Water Works Association, Vol. 105, No. 9.
18. Friedman, K. 2013. Simulation/Optimization of Alternative Water Supply Planning Using Parcel Level Demand Estimation and Management Strategies. Ph.D. Dissertation, Dept. of Environmental Engineering Sciences, U. of Florida, Gainesville, FL.

Title. Sustainable Urban Infrastructure and Water Loss Management Including a Case Study of Sanford Florida

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Research Category. Engineering

Keywords. Urban water, demand management, water loss control, water use efficiency modeling

Abstract. Continued growth in water demand in many parts of the country including Florida has placed significant stress on traditional groundwater and surface water sources for urban water supply. Regional water supply assessments by the water management districts have shown significant negative impacts of these developments including lowered groundwater tables accompanied by reduced flows in rivers and springs, declining lake levels, and increasing nutrient loads on receiving waters. In response to these problems, water utilities are required to evaluate alternative water supplies and water conservation to meet future water needs. Water losses on the utility side of the customer meters can be as high as 15-20%. A similar loss range exists on the customer side of the meter. Improved methods of water loss control can reduce these losses to 5% or less. The City of Sanford will be used as a case study to evaluate innovative methods of water loss control and the addition of water conservation practices. The EZ Guide 2.0 model will be refined to address these needs to find cost-effective solutions. EZ Guide 2.0 has been developed by the Conserve Florida Water Clearinghouse to find the optimal portfolio of traditional and alternative water supply options and demand management.
The work elements for this effort include:

- Evaluate water consumption data using property appraisal attributes and typical water use benchmarks for indoor and outdoor use to determine water saving potential.
- Evaluate commercial, industrial, and institutional water use and water savings potential
- Perform water audit and estimate water losses and trends using automatic meter reading data.
- Inventory water infrastructure, ages, and historical leakage events.
- Develop relationships and refined methods for calculating real and apparent losses from sources to distribution system.
- Apply hydraulic modeling and other analysis to isolate areas of concern and further study.
- Evaluate benefits of master and customer meter change-out program.
- Evaluate effectiveness of other conservation BMPs and compare against new BMPs using the Conserve Florida Water Guide Version 2.0.
- Estimate the economically optimal level of water losses in the treatment and distribution systems.
- Develop trends, criteria and thresholds to establish water-saving goals.

The results will be published in refereed journals as part of doctoral research by three students.

One of the primary water uses in urban areas is irrigation. The increasing use of in-ground irrigation systems has drastically altered the use of water in the urban landscape. In-ground irrigation system installations have increased exponentially since they became widely available in the 1980s and are approaching saturation in new home construction. This availability of automated irrigation systems has increased the water demand for urban irrigation by allowing homeowners to easily water their entire yard on the days of their choosing. This use is typically highly seasonal and during the peak irrigation season often exceeds the indoor use, sometimes by several times. Because of the nearly ubiquitous nature of in-ground irrigation systems in new homes and frequent retro-fitting of older homes, larger average and much larger peak demands have been placed on municipal water systems. These demands follow both a seasonal and a diurnal cycle. The irrigation demand has caused an increased pressure on both the treatment systems and distribution systems, as well additional impacts on the environment. To mitigate the impact of additional aquifer withdrawals and to remove users from the potable water systems, many communities, including Sanford, are increasing the use of reclaimed water for irrigation. The use of reclaimed water requires an additional distribution system, but when installed allows irrigation demands to be met by non-potable water on a system that demands less reliability than the potable water system. This removal of irrigation uses can allow municipalities to alter their operation which can have the added benefit of reducing water system losses.

When reclaimed water is available at low or no cost the resource tends to be used at a higher rate than equivalent users on the potable water system. This is not surprising since residential potable water bills can easily be in the hundreds of dollars if large irrigation use is occurring on the potable water system. The City of Sanford is unusual in that a large number of its users (>2,400) have been served by a reclaimed water system for years. Additionally, Sanford meters these customers and charges a small cost for water use on the reclaimed system. This unique dataset provides information on use patterns and trends among reclaimed water users that can be compared against other water users. Sanford also has more than 100 users with irrigation meters. These are users on the potable water system that have a separate meter for their irrigation systems. As with the reclaimed users these users typically have higher water use because the additional cost of a separate meter usually limits this installation to more affluent property owners. This dataset provides for an accurate comparison between reclaimed and potable water irrigation users.

One potential downside of irrigation with reclaimed water is the potential increase in stormwater runoff that over-irrigation can cause. With no- or low-cost reclaimed water, users tend to irrigate more than they might otherwise. This additional application can contribute directly to runoff if irrigation systems apply more water than can infiltrate or have over-spray onto impervious surfaces. Also irrigation systems may not have a properly installed rain sensor to shut off the system when rainfall occurs. In this scenario irrigation can actually occur during or immediately after rainfall events greatly increasing the potential for runoff. Even when properly installed and set with a functional rain or soil moisture sensor, irrigation systems can still contribute to increased runoff by filling available soil storage and limiting the available capacity in the event of rainfall.

Statement of regional or State water problem. Improved water use efficiency is an integral component of sustainable urban water systems. Some traditional sources of water have been mined beyond their safe yield and have caused problems in terms of reduced surface flows and increased pollutant levels. Utilities in Florida, Georgia, and elsewhere are now required to develop quantifiable water conservation plans that can be part of their portfolio of options to meet future water needs.

Increased water use is placing a growing burden on already strained water resources in the southeast and nationwide. Innovative ideas are being used to combat this problem by increasing the reuse of water that was pumped for potable water use. Reclaimed water systems are increasing in prevalence in Florida to combat additional pumping of aquifers. While reclaimed water use does decrease the required pumping it is important to evaluate whether it can have adverse impacts on other portions of the hydrologic water budget. Stormwater control has been and remains an important component of water resources management in Florida. Reclaimed water users tend to irrigate at a higher rate than potable users due to the low-cost or free water. This water use can cause the unintended consequence of increased runoff.

Statement of results or benefits. Florida may be unique in having a statewide database of attributes of every one of its nine million parcels of land. We are linking this information with customer water use billing records to determine the optimal mix of demand management practices. This parcel data can be combined with billing data to provide a dataset that can be used to estimate water use and water application rates. Sanford is unique in that many users are on metered reuse accounts that allow for irrigation application to be evaluated at the parcel scale. The Seminole County Property Appraiser has developed a GIS dataset for the county that includes the area of each parcel that is covered by impervious surfaces. This data can be used to develop a parcel-level water budget to evaluate the impact of irrigation on runoff. These new techniques will be incorporated into EZ Guide software for use by water utilities and other water agencies

Nature, scope, and objectives of the project, including a timeline of activities. The schedule of activities is shown below.

1. Review the literature on reuse systems in general and in Florida in particular.
2. Develop a methodology for regional water supply planning to estimate outdoor water use for utilities as the residual water use from an aggregate monthly water budget analysis for the major sectors.

Table 1. Task schedule for the project.

ID	Task	Quarter															
		Year 1				Year 2				Year 3				Year 4			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Initial bottom up evaluation of water loss, water conservation, and water reuse saving potential using EZ Guide	X	X														
2	Perform water audit and estimate water losses and trends using AMR and other data			X	X	X	X	X	X	X							
3	Refined bottom up benefit-cost optimization of water loss,water conservation, and water reuse options using EZ Guide							X	X	X	X						
4	Estimate the economically optimal level of water losses in the treatment and distribution systems									X	X	X					
5	Develop trends, criteria and thresholds to establish water-saving goals for water loss program										X	X	X				
6	Review the literature on reuse systems in general and Florida in particular													X	X		
7	Develop a methodology for regional water supply planning to estimated outdoor water use for utilities as the residual water use from an aggregate monthly water budget for the major sectors														X	X	X
8	Progress Reports	X	X	X	X	X	X	X	X	X	X	X	X		X		
9	Final Reports				X				X				X				X

Methods, procedures, and facilities. The Conserve Florida Water Clearinghouse (www.conservefloridawater.org) has developed numerous tools for evaluating water loss and water conservation best management practices. Detailed information about these activities is available at their web site. The current staff of the Clearinghouse includes a lead faculty member, one project manager, three PhD students, an undergraduate student, a systems engineer, and a programmer.

Major Findings and accomplishments. The primary tasks for year 3 are shown above in table 1. The status of these two tasks is described below.

1. 1. Estimate the economically optimal level of water losses in the treatment and distribution systems

Based on a detailed review of water loss analysis methods, a modified version of the standardized water audit recommended by the American Water Works Association was utilized as a framework to analyze water losses in Sanford. Results from these detailed data driven analyses of water losses and customer demands in Sanford were compared to results obtained from existing estimates at the start of the project to demonstrate value added from project refinements. Next, a detailed water audit was compiled to better determine monthly and annual water loss and water usage trends in Sanford as compared to the initial evaluation. UF worked in collaboration with Sanford and Jones Edmunds, Inc. on compiling and analyzing relevant data needed to conduct the water audit. This included the generation of a water use and property attribute database for 15,102 parcels in Sanford. This data is then utilized to complete the standardized American Water Works Association M36 audit, quantifying each input in detail, and determining residual total and real (physical) losses.

After the detailed audit, a process level analysis of water loss, water usage, water reuse, and demand management options could be determined. This includes methodologies for analyzing infrastructure asset data as well as pressure variability and main break history to understand the process level mechanisms behind system leakage at the individual pipe level. A component analysis is presented which breaks down real losses, as determined from the detailed water audit, into background leakage, reported breaks, and unreported breaks. Additionally, a refined analysis of customer demand patterns was performed utilizing the generated parcel level customer database along with EZ Guide.

Once the detailed process level analysis was completed, the economically optimal level of water loss control and demand management for Sanford was evaluated which was then utilized to develop a proposed implementation plan which will feed into the performance tracking system to provide continuous feedback on the actual performance of the system. Priority pipe clusters were determined based on pipe attributes as well as spatial location allowing for evaluation of the economic feasibility of water loss savings potential from active leakage detection of distribution system mains. A marginal cost curve of water loss savings associated with active leakage detection is then presented. In addition to water loss reduction, cost effective strategies for demand management were analyzed in detail using EZ Guide. A calibrated EZ Guide for the representative 2010 year provides a realistic breakdown of customer demand by end uses, which forms the basis of demand management BMP analysis. EZ Guide sorts each BMP option by cost effectiveness to develop a marginal cost curve for water savings from demand management BMPs. These results are then combined with water loss management options to develop a final recommended combined leak detection and customer demand BMP program for Sanford. This is accomplished by comparing both demand management and water loss reduction strategies as a means to reduce existing water produced vs. the cost of providing an alternative water supply. Based on these results, a proposed water loss and demand reduction implementation plan was presented as well recommended action items for future studies.

2. Develop trends, criteria and thresholds to establish water-saving goals for water loss program

The final calibrated EZ Guide evaluation of customer demand patterns for the representative year (2010), shown in Table 2, indicates that single family residential is the largest demand sector with little potable irrigation due to the prevalence of reuse irrigation water in Sanford. Sanford also has significant commercial, institutional, and industrial usage, comprising 27.2% of total usage in 2010. Additionally, Sanford's annual percent water loss has declined from 22% in 2009, 18%, in 2010, and 11% losses in 2011. These observed declines are due, in part, to the ongoing meter replacement and infrastructure rehabilitation efforts by the City of Sanford to control water losses.

However, understanding and managing the detailed nature of water losses in Sanford remains an ongoing effort which can utilize the analysis methodologies presented in this report as a template for future evaluations with improved accuracy as Cityworks becomes populated with system performance data such as pipe leakage and repair records. This framework to analyze Sanford's customer demands and water losses can be utilized by other utilities seeking to accomplish similar goals.

Table 2. Final calibrated EZ Guide based on 2010 conditions in Sanford

Sector	% Water Use	Residential gpcd	Gross gpcd	Population
Single Family	39.8%	79	55	34,652
Single Family- Indoor	33.8%	67	46	-
Single Family- Outdoor	6.1%	12	8	-
Multi-Family	15.0%	66	20	15,534
CII	27.2%	-	37	-
Commercial	11.7%	-	16	-
Industrial	3.6%	-	5	-
Institutional	11.9%	-	16	-
Unaccounted	18.0%	-	25	-
Total	100.0%	-	137	50,186

A detailed, bottom up, evaluation determined that 1.7 million gallons per day (mgd) from demand management and 0.68 mgd from active leakage detection could be cost effectively saved for a marginal cost of under $3/1,000 gallons. The total cost of implementing the full plan would be $8.5 million for demand management and $25,500/yr or $1,785,000 over a 70 year lifespan of a typical water main in Sanford. Additionally, an estimated 0.46 mgd is estimated to be saved from the ongoing meter replacement program. Therefore, a total savings potential of 2.84 mgd can be obtained from combined demand management and water loss control.

The City of Sanford has begun implementing the initial phases of its leakage detection efforts utilizing noise correlation technology in select priority areas with high expected leakage. Also, the City is exploring alternative monitoring and detection technologies. Additionally, several pipe rehabilitation projects have been completed utilizing pipe bursting with many more scheduled over the next several years to address Sanford's aging water infrastructure. Given estimated service lives of mains, a replacement analysis was performed comparing projected new pipe added with existing pipe retrofit due to service life attrition. Based on historical trends, a 1% annual growth of new pipes was assumed from 2012-2050. Figure 1 shows that the pipe replacement needs have increased in recent years and are projected to continue to increase as much of the original pipe infrastructure that was installed in the 1940s and 1950s is now due for replacement. As of 2012, 22% of pipes installed in Sanford are retrofits whereas 36% of pipes are projected to be retrofits in 2050. Additionally, Sanford is continuing its meter replacement and re-sizing program, with all residential meters projected to be done by the end of 2013 and all large multi-family and commercial meters to be completed within the next few years.

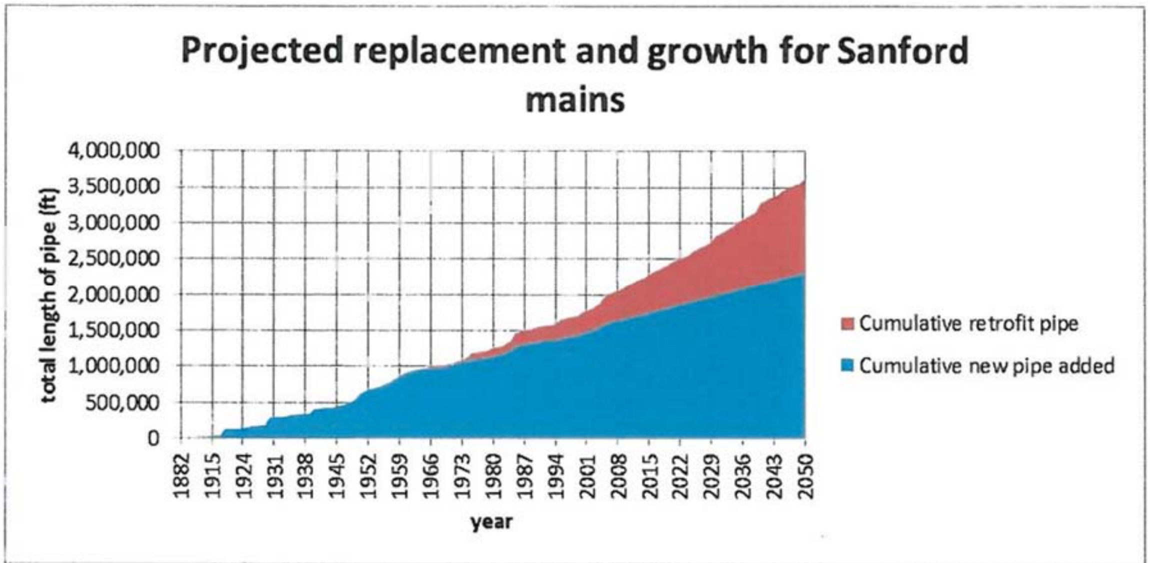

Figure 1. Projected replacement and growth of Sanford water mains.

<u>Training</u> The number of graduate and undergraduate students, by degree level, that have received training on this project are listed below.

1. Kenneth Friedman, PhD student. Optimization of urban water systems
2. Miguel Morales, PhD student. Sustainable urban water-energy systems
3. Scott Knight, PhD student. Integrated water supply-storm water management systems

Watershed Management in the face of EPA

Basic Information

Title:	Watershed Management in the face of EPA
Project Number:	2011FL270B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	3
Research Category:	Water Quality
Focus Category:	Sediments, Law, Institutions, and Policy, Management and Planning
Descriptors:	None
Principal Investigators:	Wendy D Graham

Publications

1. Reijo, C.; Arnold, T.E.; Burkett, V.; Henson, W.R.; Laing, J.M.; Weinkam, G. 2012. Characterization of Nutrient Uptake Kinetics in a Spring-fed North Florida Stream. Poster presented at the 3rd Annual University of Florida Water Institute Symposium: Nutrient Dynamics, Policy, and Management in Watersheds. Gainesville, FL, Feb. 2012.
2. Henson, W.R. and Niswonger, R.G, Evaluating the Effects of Horizontal Spatial Discretization on Interflow in the Soil Zone Using the Richards and Groundwater Flow Equations, poster Presented at the Fall AGU Conference, San Francisco, CA, Dec. 2011.
3. Cohen, M.C., Henson W.R., Petitt, C. Burkett, V., Weinkam, G., Laing, J.M. Reijo, C. and Arnold, T. E. Nutrient Spiraling in a Bottomland Sub-Tropical Stream. 9th INTECOL International Wetlands Conference, Orlando FL, June 2012.
4. Henson W.R., DeRooij, R., Graham, W.D., Examining the Role of Aquifer Confinement and Model Discretization on Spring Water Discharge and Matrix-Conduit Exchange: Implications for Nutrient Fate and Transport. International Association of Hydrologists Groundwater Quality Conference. Gainesville, FL. April 2013.
5. Henson W.R., Graham, W.D., and Cohen, M.J, Examining the Spatial Distribution of Denitrification in the Upper Floridan Aquifer Using Aquifer Geochemistry and Isotopes of Nitrate. Poster Presentation at Geological Society of America Annual Meeting October 2013.
6. Henson, W.R., Medina, R.L., Mayers, C.J., Niswonger, R.G., and Regan, R.S., 2013, CRT Cascade Routing Tool to define and visualize flow paths for grid-based watershed models: U.S. Geological Survey Techniques and Methods 6-D2, 28 p.
7. Wangusi, N., Kiker, G., Muñoz-Carpena, R., and Henson, W.R., 2013, Improving watershed decisions using run-off and yield models at different simulation scales, Environmental Systems and Decisions, September 2013, Volume 33, Issue 3, pp 440-456.

TITLE. Watershed Management in the face of EPA's New Numeric Nutrient Criteria for Florida Waters

PRINCIPAL INVESTIGATOR.
Dr. Wendy Graham, Agricultural and Biological Engineering - Hydrologic Processes

COOPERATORS:
Dr. Mark Brenner, Geological Sciences - Paleolimnology
Dr. Mark Brown, Environmental Engineering Sciences – Systems Modeling
Dr. Mark Clark, Soil and Water Science - Nutrient Best Management Practices
Dr. Matt Cohen, Forest Resources and Conservation – Riverine Nutrient Dynamics
Dr. Tom Frazer, Forest Resources and Conservation – Ecological Consequences of Nutrient Enrichment
Richard Hamann, J.D., College of Law - Environmental Law

RESEARCH CATEGORY. Water Quality

KEYWORDS. Numeric Nutrient Criteria, Paleolimnology, Best Management Practices, Hydrologic Processes, Riverine Nutrient Dynamics, Aquatic Ecology, Systems Modeling

ABSTRACT.
The overall goal of this project is to fund an interdisciplinary cohort of 6 Ph. D. Fellows to develop the new knowledge, and creative engineering, management and policy solutions needed to establish and achieve numeric nutrient criteria (NNC) for Florida's waters. Funding for 4 Ph. D. Fellows has been provided by the University of Florida under the Water Institute Graduate Fellows program. **In this proposal, partial funding for 2 additional Ph. D. students is requested from the USGS to add additional expertise in the areas of hydrologic processes and aquatic ecology**. The education and research of each Fellow evolves from specific problems and research questions related to management of Florida's water and watersheds under NNC. The unique cross-disciplinary environment of our program allows an integrated whole that will reflect disciplinary facets associated with this complex problem. Components currently funded by UF include Paleolimnology, Nutrient Best Management Practices, Riverine Nutrient Processing, and Systems Modeling (Original Proposal PIs Brown, Brenner, Clark, Cohen, Hamann). This proposal will fund additional components in either Hydrologic Processes or Aquatic Ecology (Graham and Frazer, respectively).

STATEMENT OF REGIONAL OR STATE WATER PROBLEM.
In January 2010 the US Environmental Protection Agency embarked on a new approach to regulate nutrient pollution in aquatic ecosystems. Previously, nutrients were managed according to narrative criteria that categorized water bodies as impaired using observed biological responses, specifically an imbalance in the native flora and fauna of the aquatic ecosystem. Now, rather than waiting for biological impairment to become apparent before implementing ecologically protective nutrient levels, EPA will regulate nutrients according to now finalized numeric criteria (http://water.epa.gov/lawsregs/rulesregs/upload/floridaprepub.pdf). Under this plan, concentration thresholds will be established for each water body type (i.e., lakes, wetlands, rivers/streams, springs, estuaries, and canals) and enforced uniformly statewide.

This new approach constitutes a paradigm shift that has generated significant controversy. On one hand, it offers a simple metric for the regulatory process, and which may accelerate the timeline for listing and restoring degraded water bodies. It is also pre-emptive, reducing the risk of tipping water bodies into a degraded state that is often irreversible. On the other hand, it ignores the site-specificity that was an important component of narrative standards. Each river, lake and estuary is different, and adoption of a single standard is therefore "under-protective" of some systems and "over-protective" of others. The basis for setting such thresholds is fraught with uncertainty. Although development of alternative site-specific criteria can be petitioned, the cost and time associated with gathering such additional data to modify numeric values for a particular water body will be considerable. Therefore, the proposed approach, while conferring simplicity and predictability will also create rigidity that precludes adaptation and optimization.

Adoption of numeric standards is intended to be a national endeavor, enacted on a state-by-state basis. In Florida, adoption of numeric criteria is contentious, in large part because of the number and wide diversity of water bodies in the state. The process unfolding now in Florida will undoubtedly influence how other states manage their surface water resources. This developing environmental management strategy provides an opportunity to provide guidance and rigorous oversight of the process. Graduate students trained in the crucible of this controversy, and engaged in the dialog it has engendered, will be well equipped to solve the trans-disciplinary problems associated with water resource conflict all over the world.

The currently funded Water Institute Graduate Fellows (WIGF) program links faculty and students from watershed science (Cohen), limnology (Brenner), wetlands and water quality extension (Clark), water law (Hamann), and systems modeling (Brown) to study the scientific basis for, and the design and implementation of numeric nutrient criteria for Florida waters. The USGS 104B funding extends these links to include hydrologic science (Graham), and aquatic ecology (Frazer), facets that obviously impact the design and implementation of numeric nutrient criteria.

STATEMENT OF RESULTS OR BENEFITS.

The WIGF program will provide a greater understanding and framework to address issues of water and watersheds and the interplay of policy and science required to manage them. The program will build a firm disciplinary base (each student's major), overlay coursework in complementary disciplines, and incorporate interdisciplinary training and research experiences. Specifically, this program will:

(1) Use a synthetic approach to understanding watershed-scale nutrient dynamics through the application of models, field measurements, and data mining.
(2) Explore effectiveness of best management practices for reducing nutrient loads.
(3) Explore the local-scale couplings and feedbacks among climate, land-use, water use, and nutrient cycling in watersheds, and how these relationships scale-up to affect nutrient fluxes to springs, lakes, wetlands and estuaries.
(4) Understand the effects of increased nutrient delivery on key biogeochemical and ecological processes that, in turn, influence the structure and function of aquatic ecosystems.
(5) Quantify nutrient uptake and recycling kinetics in streams and rivers to provide a needed quantitative foundation for establishment of downstream protective values (DPVs).
(6) Combine paleolimnological techniques with modeling approaches to develop reference (pre-disturbance) conditions for lakes.

Three primary outcomes of the program include:

(1) Education and training of 6 Ph .D. scientists and engineers to prepare them for the challenges of managing water and watersheds.
(2) Increased scientific understanding of the relationships between and uncertainty associated with watershed nutrient dynamics and ecological conditions in Florida waters.
(3) Provision of biophysical, social science and policy perspectives grounded in Florida water law toward a national effort to apply numeric nutrient criteria to surface waters.

Other features include institutionalization of cross-disciplinary research and education, internationalization of student perspectives, blending of disciplines in doctoral training, and dissemination of results within and outside traditional academic circles.

NATURE, SCOPE, AND OBJECTIVES OF THE PROJECT, INCLUDING A TIMELINE OF ACTIVITIES.

Our broadest goal is to develop a graduate program that stresses integration of engineering, biophysical, and social sciences and addresses issues related to management of water and watersheds through field-based teaching and research. The program consists of three elements:

Education **-** The educational experience fostered by this program will complement the disciplinary focus of each student's own research. The program will blend experiential learning and academic course work. A core set of interdisciplinary courses (some developed by the former UF NSF-funded IGERT in Adaptive Management) will be required of each student, regardless of discipline or major. A weekly seminar involving both faculty and students will focus on combining social, ethical and scientific domains as they relate to the program's focus using a Socratic format of inquiry and debate between participants to stimulate critical thinking and to illuminate ideas.

Research **-** We have identified a significant water management issue, numeric nutrient criteria (NNC), as the central topic around which our program will be constructed. The education and research experience of each student will evolve from and be shaped by specific problems and research questions related to adaptive management of Florida's water and watersheds under NNC. During the 1st fall semester we will devote our weekly Socratic seminar to identifying study watersheds and developing a scope of work addressing the research approach. The product of this will be a multi-authored "research report" that outlines the major watershed issues. Each student will draw from this experience in formulating his/her research topic.

Service **-** We will foster a component of ethical responsibility and civic involvement, which will be reinforced in core coursework and our continuing biweekly seminar that integrates ethics, communication, and leadership skills with research methods, scientific inquiry, and engineering practice. We anticipate involving undergraduates in studios, research, and special programs (including field trips) under mentorship of our graduate students. Finally, we will encourage students to get involved in community projects and education initiatives (e.g. watershed working groups) related to program objectives on a volunteer basis.

Project Outcome Timeline-

Student Recruitment (December, 2010 – February, 2011) – Each faculty member will be responsible for recruiting within his or her discipline. We will develop a brochure and web ad that showcases our WIGF Program for placement on various academic and professional web sites. In addition, we will advertise on the IGERT web site. We anticipate inviting students to UF campus in mid-February to mid-March. (All faculty members will participate)

Cohort Building Exercise I (August 2011) – **Natural and Degraded Systems of Florida.**
Similar to the "Everglades course" developed for the UF-IGERT, we will develop a 2-week course that will show case natural and degraded watersheds in north and central Florida. (All faculty members will participate)

Socratic Seminar (Fall 2011 and Spring 2012) - This weekly 3 hour seminar is required each semester. In the first year, we will focus on a synthetic dialog related to the cohort's research agenda that will ultimately lead to development of a large integrative proposal. In later years the seminar will be used to focus student research questions. (All faculty members will participate)

Cohort Building Exercise II (Feb 2012) – Water Institute Symposium. Students will work with Water Institute staff in planning and developing a two-day Symposium at UF that will bring together scientists, managers, and policy experts to discuss watershed management and NNC.

Watershed Management & Restoration course (Summer 2012) – Modeled after the Watersheds course developed for the UF-IGERT, this required course will be team taught by WIGF Program faculty. (All faculty members will participate)

Cohort Building Exercise III (July-August 2012) –**Writeshop.** This writing workshop will be conducted following Summer 2012 as the culmination of the Socratic seminar; students and faculty will cloister at a location and write a major integrative proposal for submission in Fall 2012 to one of the following NSF programs: NSF-Biocomplexity, NSF-IGERT, NSF-WSC, NSF- CNH, NSF-Environmental Engineering, NSF- Hydrologic Sciences. (All faculty members will participate)

METHODS, PROCEDURES, AND FACILITIES.

The research theme addresses complex and emerging issues related to the management, protection, and regulation of nutrients in Florida watersheds. The US-EPA's proposed Numeric Nutrient Criteria (NNC) will have significant impacts on all sectors of Florida's economy including, industries discharging pollutants to lakes and flowing waters, publicly owned water treatment facilities, public and private storm water management agencies, and agriculture. It will require rethinking the way in which point source and non-point source discharges are dealt with as well as the institutional frameworks of governance and regulation that manage them. Real, cost-effective solutions, and public willingness to address the issue, will require not only the talent and efforts of Florida planners, designers, engineers and scientists, but an adaptive approach to implementation that adequately addresses scientific uncertainty and adapts to complex local conditions. Our research theme will address both the biophysical science and social policy dimensions of watershed research related to NNC.

We will use an experiential, multidisciplinary field-based program of research to study watersheds comparing nutrient dynamics, land use impacts, and management alternatives. Our goal is to provide quantitative science in support of flexible NNCs. There are already research programs underway at UF, with others proposed, and this WIGF Program will build on these existing initiatives. The watersheds will be identified in the first weeks of the program. The final decision will take into consideration the potential for synergistic activities with proposed and ongoing research initiatives at, for instance, the Santa Fe River basin, Newnans Lake, Lake Apopka, and Lake Alice. A key feature that ties our research theme to our educational/training program is integration of experiential, field-based research, whereby all students and faculty members on the team participate in field data collection, public management meetings (e.g., basin working groups, NNC public meetings) and weekly core seminars. Thus, we ensure integration across disciplines and a holistic perspective by each member of the team.

Field Campaigns - Our field research efforts will be organized into field campaigns in which all members of the program team participate. Campaigns will include such activities as water quality sampling, lake sediment coring, diurnal productivity measurements, administering stakeholder questionnaires, stormwater sampling, etc. Each campaign will be designed to collect data that will be used by one or more graduate students in their research projects. Each fellow/faculty team will be responsible for organizing filed campaigns as their research efforts take shape. This will help fellows develop skills in research design, management, and execution.

MAJOR FINDINGS AND ACCOMPLISHMENTS

Programmatic Accomplishments:

A national recruiting effort for the Water Institute Graduate Fellow (WIGF) cohort was conducted from December 2010 to February 2011. A total of 133 candidates applied for these fellowships, and the faculty team identified 17 excellent candidates from the pool. Eight of these candidates were invited to Gainesville during March 4-7th 2011 to participate in a recruitment weekend. Offers were made to 7 of these candidates and all accepted and enrolled in UF. The GPAs of the enrolled fellows ranged from 3.8 to 4.0 (mean 3.91) and the GREs ranged from 1100 to 1400 (mean 1270). One of the candidates has since withdrawn for personal reasons. The 2011 WIGF cohort now includes:

Tom Arnold (BS Penn State, MS UF, Advisor Mark Brenner, Geological Sciences)
Resources and Conservation)
Wesley Henson (BS/MS University of Nevada Reno, Advisor Wendy Graham, Agricultural and Biological Engineering)*
Joelle Liang (BS Berry College, MS North Carolina State University, Advisor Tom Frazer, Interdisciplinary Ecology)*
Charlie Nealis (BS/MS UF, Advisor Mark Clark, Soil and Water Sciences)
Courtney Riejo (BS Carroll University, MS Virginia Tech, Advisor Matt Cohen, Forest
Chris Pettit (BS New College, JD UF, Advisor Christine Overdevest, Environmental Sociology)
Grant Weinkam (BS Ohio University, MS University of Cincinnati, Advisor Mark Brown, Environmental Engineering Sciences)

*partially supported by USGS 104B grant.

During the Fall 2011 semester the WIGF faculty and student cohort participated in a 4 day group field trip around the state of Florida focused on visiting Natural and Degraded Systems of Florida and initiated a weekly Socratic Seminar (Fall 2011) to provide a synthetic dialog to refine the cohort's research agenda. The WIGF student cohort also assisted in the planning of the February 2012 Water Institute Symposium.

During Fall 2011 and Spring 2012 the students conducted a Tracer Additions for Spiraling Curve Characterization (TASCC) experiment (Covino et al. (2010)) to a low relief, spring-fed stream in Florida. Previously, the method has been tested only in mountain streams in the western United States. Using this robust methodology, the students successfully characterized the saturation kinetic curve of nitrogen through stream dosing experiments and presented research results at the 3rd Annual University of Florida Water Institute Symposium poster session as well as the 9th Annual INTECOL International Wetlands Conference.

During the Spring 2012 semester the weekly Socratic Seminar continued and the WIGF fellows helped host the Water Institute Symposium (Feb 15-16th, 2012). A two-day retreat was conducted in May 2012 during which the WIGF faculty and student cohort developed an integrative framework for their proposed individual Ph. D. work on nutrient dynamics, management and policy.

During the Summer 2012 semester the WIGF faculty and student cohort participated in the 5-week UF Law School Costa Rica Study abroad program. The WIGF students, in collaboration with UF Law Students and Costa Rican Law Students, worked on a variety of project, each of which focused on water management issues pertinent to the Tempisque-Bebedero Basin, one of Costa Rica's largest and most water-limited watersheds. The Tempisque-Bebedero Basin and the Pacific Coast of Central America has been characterized as a "climate change hot-spot" due to predicted impacts on water resources, principally drought.

The 2012 projects included an investigation of the legal, socioeconomic, and environmental issues associated with rice production in the buffer zone of Palo Verde National Park; an assessment of the legal and scientific tools available for improving the health of the impaired wetland at Palo Verde National Park, an internationally recognized wetland; and an analysis of the institutional and legal framework for drought management in the Tempisque Basin. Participants also evaluated new recommendations for establishing minimum environmental flows in the Basin, investigated the environmental and social impacts of a proposed water storage dam in the Basin, and reviewed and critiqued current regulations for nutrient pollution in the Tempisque River. See http://www.law.ufl.edu/academics/academic-programs/study-abroad/summer-abroad/costa-rica/project-spotlight for detailed reports on the 2012 projects.

During the Fall 2012 semesters the WIGF students presented and defended their individual Ph. D. research proposals. The following proposals were approved by the students' supervisory committees

Student: T. Elliott Arnold, Ph. D. in Geological Sciencse, College of Liberal Arts and Sciences. Anticipated graduation date May 2015.
Proposed Dissertation Title: Estimating groundwater discharge into lakes via stable isotope and radium mass balance equations: Redefining nutrient budgets and nutrient sources.

Student: Wesley Henson, Ph. D. in Agricultural and Biological Engineering, College of Agricultural and Life Sciences and College of Engineering. Anticipated graduation date May 2015.
Proposed Dissertation Title: Examining the influence of water fluxes, flow paths and age on Nutrient Delivery: Implications for North Florida Springs.

Student: Joelle Liang, Ph. D. in Interdisciplinary Ecology, School of Natural Resources and the Environment. Anticipated graduation date May 2015.
Proposed Dissertation Title: Biogeochemistry and nutrient availability at the sediment-water interface in Florida springs and implications for management.

Student: Charles Nealis, Ph. D. in Soil and Water Sciences, College of Agricultural and Life Sciences. Anticipated graduation date May 2015.
Proposed Dissertation Title: Barriers and motivators to implementation of urban BMPs.

Student: Courtney Reijo, Ph. D. in Forest Resources and Conservation, College of Agricultural and Life Sciences. Anticipated graduation date May 2015.
Proposed Dissertation Title: Eutrophication in flowing waters: Metrics of nutrient limitation and processing in rivers.

Student: Grant Weinkam, Ph. D. in Environmental Engineering Sciences,. Anticipated graduation date May 2015.
Proposed Dissertation Title: Fate and future of phosphorus loading associated with land applied

reclaimed water in Florida.

During the of Fall 2013 and 2014 the WIGF student cohort co-instructed an honors-level undergraduate course entitled Environmental Issues in Water Resources. With a focus on water resource issues in the state of Florida, each fellow instructed a two-week section on material from his or her discipline and engaged the students in hands-on learning and discussion. At the end of each section, the instructors brought the students on a partial or full-day field trip to sites in north Florida which built upon the concepts presented in the section and introduced the students to local hydrology, current environmental issues, and ongoing restoration efforts. Throughout the course the instructors emphasized the importance of interdisciplinary collaboration when addressing issues in water resources. With this in mind, students completed a final paper surveying a water resources issue of their choice from an interdisciplinary perspective. Fellows concluded with a day of discussing “the future of freshwater in Florida” by synthesizing concepts and issues from each section of the course.

Research Progress by students partially supported by this grant:

<u>Joelle Laing:</u> Following a series of tank experiments completed over the last year, Joelle Laing is now focused now on completing a field based study to assess to sediment redox conditions in several Florida springs. The primary aim of the field-based study is to evaluate the relationship between sediment redox potential, organic matter composition and SAV, the abundance of native vascular plants and nuisance macroalgae in particular. The empirical data to be generated are a necessary precursor to a manipulative experiment to test explicitly the effects of sediment redox potentail on plant performance. This work is part of Joelle’s dissertation research on the biogeochemical feedbacks contributing to the growth and success of species of submerged aquatic vegetation. The findings from her work are expected to have significant restoration implications and, as such, will be of interest to a broad suite of aquatic scientists and water resource managers.

<u>Wes Henson:</u> Wes Henson has been evaluating process-based models to examine methods for representing dual permeability domains in karst aquifers. During summer 2013, he collected field data to investigate the spatial distribution of denitrification in the upper Floridan Aquifer across a gradient of aquifer confinement, using synopotic geochemical, isotopic, dissolved noble gas and aquifer tests. His current data analyses apply multivariate statistical methods and interpretation of isotopic data to determine where denitrification may be significant in the aquifer. During 2014 Wes conducted borehole dilution tests and push-pull in-situ denitrification tests with and without carbon addition to quantify the rates of in-situ denitrification in several wells in the Upper Floridan Aquifer. Results showed significant nitrate losses occurred during the push-pull tests, and current work is investigating whether the loss was due to denitrification or assimilation. Wes’s future research will focus on how representation of conduits and conduit-matrix exchange affects heads, fluxes, spring flows and travel times from the contributing watershed to the spring in karst aquifers. These are of great importance for understanding their influence on nutrient transformation and attenuation in the Floridan Aquifer.

In addition to his research, Wes participates in several science outreach activities: teaching elementary children about geology, wetlands, and water quality; leading high school 4-H workshops on wetlands and springs; and mentoring an undergraduate student from the Agricultural and Biological Engineering department.

Conference Presentations:

1. Henson W.R., DeRooij, R., Graham, W.D., Examining the Role of Aquifer Confinement and Model Discretization on Spring Water Discharge and Matrix-Conduit Exchange: Implications for Nutrient Fate and Transport. Poster Presentation at International Association of Hydrologists Groundwater Quality Conference. Gainesville, FL. April 2013.
2. Henson W.R., Graham, W.D., and Cohen, M.J, Examining the Spatial Distribution of Denitrification in the Upper Floridan Aquifer Using Aquifer Geochemistry and Isotopes of Nitrate. Poster Presentation at Geological Society of America Annual Meeting October 2013.
3. Henson W.R., Examining Denitrification in the Upper Floridan Aquifer near Point and non-Point Sources, Poster Presentation at University of Florida Water Institute Symposium, February 2014..

Publications:

1. Henson, W.R., Medina, R.L., Mayers, C.J., Niswonger, R.G., and Regan, R.S., 2013, CRT—Cascade Routing Tool to define and visualize flow paths for grid-based watershed models: U.S. Geological Survey Techniques and Methods 6-D2, 28 p.
2. Wangusi, N., Kiker, G., Muñoz-Carpena, R., and Henson, W.R., 2013, Improving watershed decisions using run-off and yield models at different simulation scales, Environmental Systems and Decisions, September 2013, Volume 33, Issue 3, pp 440-456

Publications in Progress:

1. Henson, W.R., Niswonger R.N., DeRooij, R., and Graham, W.D., Examining the Effects of Horizontal Spatial Discretization on Runoff and Interflow in the Soil Zone at the basin scale.

TRAINING

Two Ph. D. students are partially funded under this project and will join the UF funded cohort of 4 additional Ph. D. students. Each Ph.D. student has crafted dissertation around a topic and disciplinary facet of interest to them while contributing to the team’s overall research theme of watershed management and policy in the face of Numeric Nutrient Criteria.

Development of Passive Sensor for Measuring Water and Contaminant Fluxes in the Hyporheic Zone

Basic Information

Title:	Development of Passive Sensor for Measuring Water and Contaminant Fluxes in the Hyporheic Zone
Project Number:	2013FL311B
Start Date:	2/1/2014
End Date:	3/28/2015
Funding Source:	104B
Congressional District:	3
Research Category:	Water Quality
Focus Category:	Solute Transport, Surface Water, Groundwater
Descriptors:	None
Principal Investigators:	Mark Newman, Kirk Hatfield

Publications

1. Layton, L.E., H.R. Klammler, K. Hatfield, M.D. Annable, M.A. Newman, J. Cho, R. Gonzalez. Development of a Passive Sensor for Measuring Water and Contaminant Flux in the Hyporheic Zone. 8th IAHS International Groundwater Quality Conference. April 21-26, 2013. University of Florida. Gainesville, Florida.
2. Annable, M.D., L.E. Layton, K. Hatfield, M.A. Newman, J. Cho, R. Gonzalez, H.R. Klammler. Development of a Passive Sensor for Measuring Water and Contaminant Flux in the Hyporheic Zone. University of Guelph 2013 Consortium Meeting. May 29-31 2013. University of Guelph. Guelph, Ontario.
3. Layton, L.E., H.R. Klammler, K. Hatfield, M.D. Annable, M.A. Newman, J. Cho. Development of a Passive Sensor for Measuring Water and Contaminant Flux in the Hyporheic Zone. SETAC North America 34th Annual Meeting. November 17-21, 2013. Gaylord Opryland Hotel & Convention Center. Nashville, Tennessee.
4. Annable, M.D., L.E. Layton, K. Hatfield, M.A. Newman, J. Cho, R. Gonzalez, H.R. Klammler. Initial testing of the sediment bed passive flux meter. University of Guelph 2013 Consortium Meeting. June 2-4 2014. University of Guelph. Guelph, Ontario.

Title: Development of a Passive Sensor for Measuring Water and Contaminant Fluxes in the Hyporheic Zone

Principal Investigator: Mark A. Newman, U. of Florida, markn@ufl.edu, 352-392-9537

Research Category: Engineering

Keywords: solute transport, surface water, groundwater

Abstract:
Aquatic sediments contaminated with semi-volatile organic compounds are often difficult to characterize and manage due to the tendency for the contaminants to be retained within the sediments for long periods of time due to the hydrophobic nature of some of the key compounds, such as polycyclic aromatic hydrocarbons and polychlorinated biphenyls. Technologies currently exist to identify groundwater discharge zones and infer estimates of contaminant mass flux based on total contaminant concentration in bulk sediment, though it is generally accepted that freely dissolved concentration in pore water is a better measure of potential exposure. The purpose of this research project is to demonstrate a new tool to provide more accurate characterization of sediment pore water and bioavailable contaminant fluxes through direct in-situ measurement. The hyporheic passive flux meter (PFM) is designed for passively and directly providing direct in-situ measurements of volumetric water flux and contaminant mass flux vertically through the upper surface sediment layer and into the overlying water column. The hyporheic PFM consists of an internal permeable sorbent which is impregnated with one or more water soluble tracers and is contained in a dedicated drive-point with an upper and lower screened opening. This configuration allows flow through the device if there is a pre-existing vertical gradient between the sediment bed and the water column. Once the hyporheic PFM has been deployed, the tracers are displaced from the sorbent at rates proportional to the average vertical specific discharge; thus, the mass loss of the tracers during deployment can be used to calculate specific discharge. Similarly, the cumulative mass of sorbed contaminants provide a direct measurement of the vertical contaminant flux during deployment. The hyporheic PFM prototype is currently being tested and validated through multiple bench-scale box aquifer experiments. The initial results show good agreement between the hyporheic PFM estimated and actual measured fluxes through the aquifer model. The laboratory testing will be followed by full-scale field deployments of the hyporheic PFM at sites with manageable conditions and previous contaminant characterization to demonstrate the ability to measure contaminant flux through the aquatic sediment bed.

RESEARCH PROBLEM:

The hyporheic zone comprises fluvial sediments within which there is exchange of water between a stream and the subsurface (Bencala, 2005). It is often characterized by chemical and temperature gradients that exert control on the behavior of solutes and organisms both at the interface and in the adjacent aquifer and stream environments (Brunke and Gonser, 1997; Hancock et al., 2005). It is an important zone for pollutant, energy and carbon cycling, and while there is a considerable body of knowledge about processes occurring within both rivers and aquifers, less is known about the processes that occur at the interface of these environmental compartments (EA Science Report SC050070, 2009). Contaminated sediment sites on the National Priorities List (USEPA, 1998) are often contaminated with semi-volatile organic compounds such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs). Due to the hydrophobic nature of these key contaminants, sediment contamination is particularly difficult to manage due to the tendency for contaminants to be retained within sediments for long periods of time. Characterization and management of these sites requires new tools capable of quantifying the spatial distribution of contaminant mass flux and resulting contaminant loads.
In aquatic sediment systems contaminant mass flux occurs throughout the surface water column and sediment bed as a combination of dissolved contaminant mass flux (advective and diffusive) and sorbed contaminant mass flux (associated with sediment particle flux). Within the water column, sediment transport is typically defined in terms of the sediment load where there can be dissolved load, suspended load, and bed load. Dissolved contaminant mass flux can occur throughout the water column and

sediment bed whereas sorbed contaminant mass flux is coincident with suspended and mobile surface sediment transport.

Using this conceptual model for aquatic sediment systems, it is apparent that multiple devices will be required to quantify the contaminant mass loads depending upon the relevant mechanisms for sediment and contaminant mass flux. This research is aimed at developing a new low-cost technology that will complement emerging and existing technologies (surface water PFM, groundwater PFM, UltraSeep meter, traditional sediment traps, Trident Probe, Nortek Vectrino II velocimeter, Nortek Aquadopp Profiler, and Optical Backscatter Sensor) in order to provide requisite data to quantify the contaminant flux and evaluate the contaminant mass balance within the water column and sediment bed.

The new sensor incorporates the field tested concepts of the Passive Flux Meter (PFM) a device developed at the University of Florida (US Patent 6,402,547 B1, Hatfield et al 2002 and 2004; Campbell et al. 2006—*designated the Best Technology Paper published by ES&T, 2006*). The PFM is a self-contained permeable unit that is inserted into a well where it captures target contaminants from the pore water flowing through it. The sorbent matrix is also impregnated with known amounts of one or more fluid soluble resident tracers. These tracers are leached from the sorbent at rates proportional to the water flux (specific discharge).

After a specified period of exposure to flow, the PFM is removed for sampling and the sorbent is carefully extracted to quantify the mass of all contaminants intercepted by the meter and the residual masses of all resident tracers. The contaminant masses are used to calculate time-averaged contaminant mass fluxes, while residual resident tracer masses are used to calculate cumulative water flux.

RESEARCH OBJECTIVES

The goal of this student lead seed project is to develop a new passive technology that will incorporate the field-tested concepts of the passive flux meter (PFM) to provide direct *in situ* measurements of water and contaminant fluxes within the hyporheic zone. The proposed effort will develop a new sensor, test it under controlled laboratory conditions and develop field deployment strategies. If a robust technology is developed from this seed project, follow on proposals will be generated to pursue additional funding to support further development of the novel technology. The new technology will improve the ability of site managers to formulate a site-wide contaminant mass balance, evaluate the efficacy of hyporheic zone for monitored natural attenuation, manage aquatic sediment site restoration, control private and public expectations of restoration efforts, and ensure protection of human health and the environment. Specific objectives of the proposed work include:

1. Develop a prototype technology to quantify water and contaminant fluxes within the hyporheic zone.
2. Develop procedures for deploying the prototype technology in the field and evaluate its compatible use in conjunction with emerging and existing technologies to quantify contaminant flux and evaluate the contaminant mass balance over an aquatic sediment site.

METHODS:

As a seed proposal, this project provides supplemental support to the development of a new passive technology for quantifying water and contaminant fluxes within the hyporheic sediment zone; testing the device under controlled laboratory conditions; and developing field deployment methods. The proposed work includes 2 specific tasks.

Task 1: Develop a prototype hyporheic passive flux meter.

The original groundwater PFM design has been adapted in order to measure the vertical specific discharge of water and contaminant fluxes through the hyporheic sediment zone. Each hyporheic PFM is contained in a dedicated drive-point with two screened openings. If vertical flow is present in the sediment bed, there is a vertical head gradient which drives sediment pore water to flow through the hyporheic PFM. The device contains an internal permeable sorbent which is impregnated with tracers and exposed to sediment pore water via flow between the two screens (Figure 1). During device deployment, hyporheic PFM tracers are eluted from the device at rates proportional to the average vertical specific discharge of water flowing through the sediment bed. Thus, by measuring tracer mass loss during deployment, the specific discharge may be calculated for water flowing through the sediment bed. If dissolved or complexed contaminants exist in the sediment pore water, then the cumulative mass of contaminant intercepted and retained on the hyporheic PFM sorbent can be used to determine the cumulative vertical contaminant mass flux (mass of contaminant per unit cross-sectional area). Sorption of background contaminants, to the solid sorbent (e.g. activated carbon) within the hyporheic PFM, pre-concentrates compounds prior to analysis and this substantially lowers device detection limits and improves the accuracy of flux calculations for trace contaminants. This is particularly important for higher molecular weight PAH and PCB congeners, many of which have very low aqueous solubilities.

As this is a new application, laboratory testing was conducted to characterize the performance of the hyporheic PFM. The required tasks included 1) development of transport theory following an approach developed by Klammler et al. (2011) to describe the flow of sediment water and the transport of tracers and contaminants through a vertical flux passive flux meter, 2) determine the location and size of inlet and outlet ports of the hyporheic PFM to optimize the determination of vertical specific discharge within the sediment, and 3) evaluate sorbent materials and tracers to select the optimal components for application with semi-volatile organics while taking into account flow velocities, requisite deployment durations, and high salinity issues that may affect tracer desorption or contaminant adsorption behavior.

Hyporheic PFM performance tests have been performed in laboratory flow cells for accuracy and precision in measuring cumulative vertical mass fluxes of water and dissolved contaminant. The flow cells contain prepared sediment packs and are equipped with reservoirs that can be used to apply known vertical hydraulic gradients (Figure 2). During these tests, the hyporheic PFM have been deployed for specific durations and permeated with known contaminant concentrations. Performance has been evaluated by comparing device measured specific discharges and contaminant fluxes with known specific discharges and contaminant fluxes created in the flow cell.

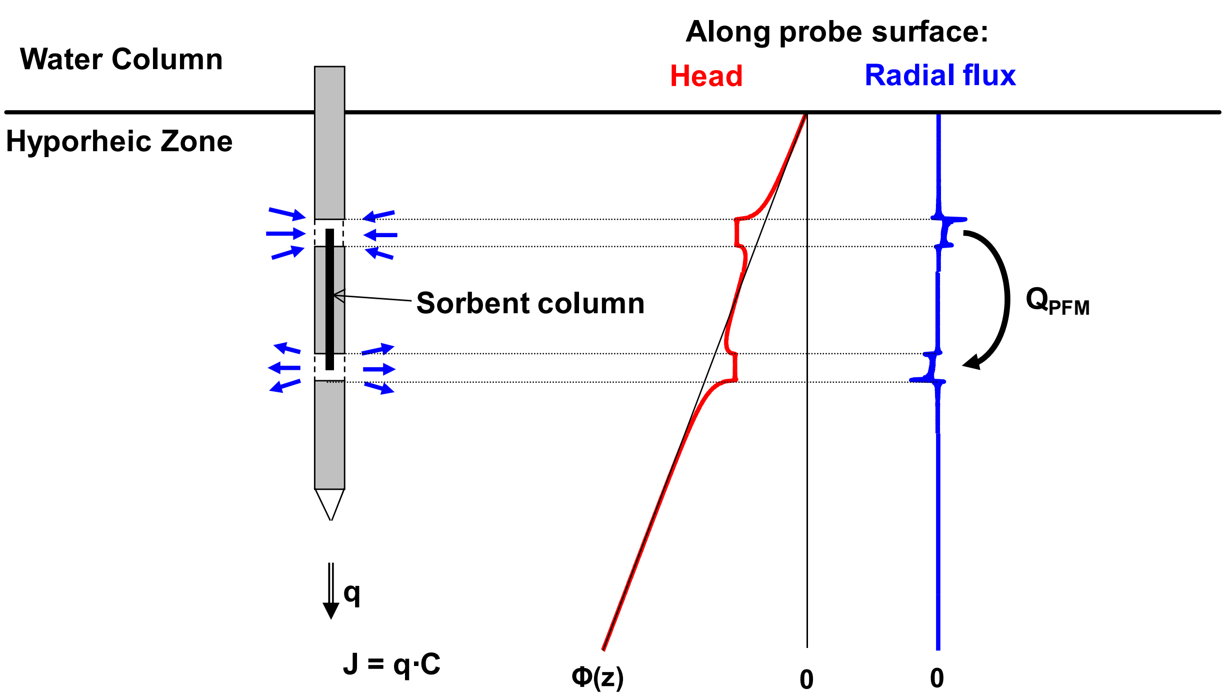

Figure 1: Hyporheic passive flux meter conceptual schematic.

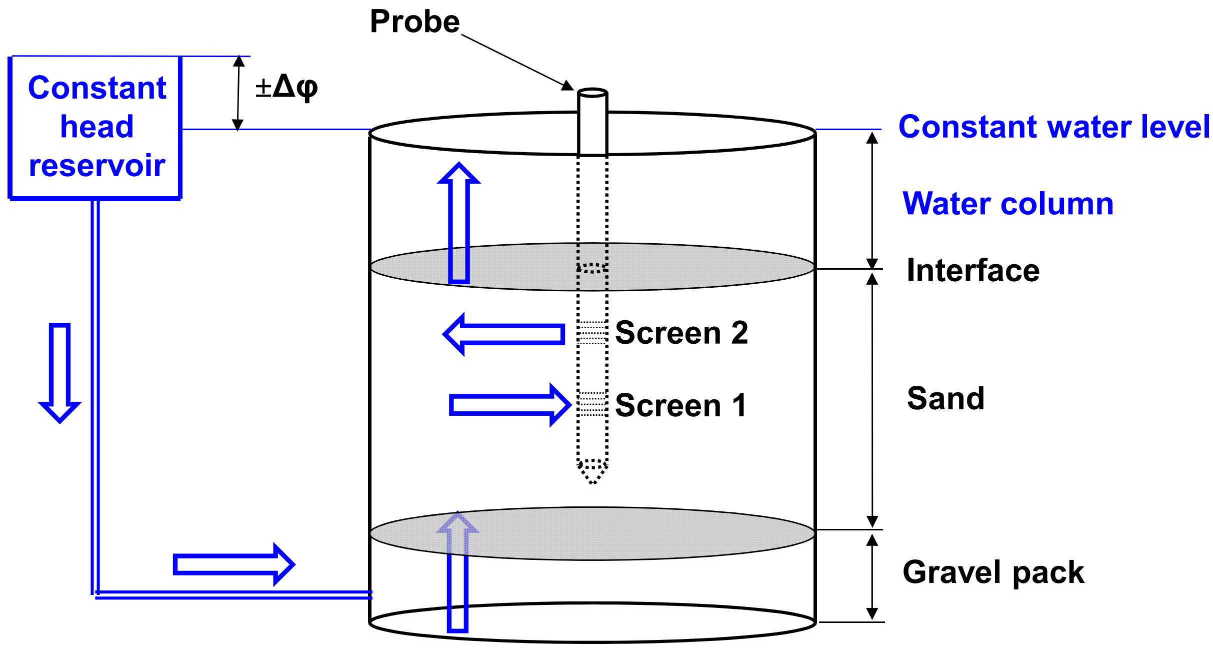

Figure 2: Flow cell for hyporheic PFM testing. Note: Current configuration is for upward flow through the sediment water interface. Relocation of the constant head reservoir can also allow for downward vertical flow through the sediment water interface.

Task 2: Sensor Integration and Deployment Testing. Develop procedures for deploying the prototype sensor in the field and evaluate its compatible use in conjunction with existing technologies to quantify contaminant flux and evaluate the contaminant mass balance within the water column and sediment bed.

YEAR 2 PRINCIPAL FINDINGS

The focus of research efforts during the second year of support was developing a device for measuring flow reversal or cyclical fluxes such as those that would be experienced in tidally influenced locations. This requires that the device be able to measure flux in both the upward and downward directions.

A total of 10 tests were performed to evaluate the capabilities of the device during flow reversal. The first two tests were run with unidirectional flow while the remaining eight had one flow reversal occur during the test. Net water flux and cumulative water flux were estimated based upon observed concentration profiles and subsequent calculation of the required moments. Net and cumulative water flux were equal to one another for the two cases of unidirectional flow. Results are shown in Figure 3 which compares the estimated net water flux to the true net ambient water flux for the two tracers 2-propanol and tert-butanol. Both tracers provided reasonable estimates for net flux with absolute error increasing with greater net water flux. Typically, tert-butanol provided more accurate estimates of the net water flux.

U.S. PATENT AWARDED (US61/969,382): Sediment Bed Passive Flux Meter, 2015.

This student-lead seed project (2013FL311B) generated a patent for a new passive technology capable of measuring water and contaminant fluxes across sediment beds in streams, rivers, lakes, and estuaries. The resulting technology has a wide range of potential applications.

TECHNOLOGY SIGNIFICANCE

Aquatic sediments are often the ultimate receptors of contaminants. Sediment contamination is particularly difficult to manage due to the tendency for contaminants to be retained within sediments for long periods of time. According to an estimate by the U.S. Environmental Protection Agency (U.S. EPA), approximately 10% or 1.2 billion cubic yards of the sediment underlying the country's surface water is sufficiently contaminated with toxic pollutants to pose potential risks to fish and to humans and wildlife that eat fish (U.S. EPA, 1998). As such, a critical research need that has been identified is development of tools for assessment of incoming off-site contaminant loads and methods to quantify how those loads might impact the surface sediment concentrations at a remediated sediment site. In most urban and industrial harbors and rivers, it is unlikely that all contaminant sources will be completely eliminated. Aquatic sediments will be exposed to continued input from such sources as permitted discharges, transport from upland or upstream contaminated sites, or from stormwater discharge. Recontamination from such sources can slow or even reverse recovery and methodologies are needed to manage for ongoing contaminant influx.

The likely applications of the new technology developed through this project may include any location where sediment quality is compromised. These include contaminated industrial sites, Federal Superfund sites, urban waterways with legacy pollution due to historic manufactured gas production and/or power generation and numerous Navy sites. Liability no longer ends with the completion of a sediment remedial action such as dredging or capping. Instead, remedial actions often require long-term management and responsible parties are increasingly interested in designing remedial actions that will be effective despite ongoing low-level contaminant loading. The technology developed through this research can be used to quantify the potential loading from such ongoing sources, so that the load can be attenuated by the chosen remedial alternative.

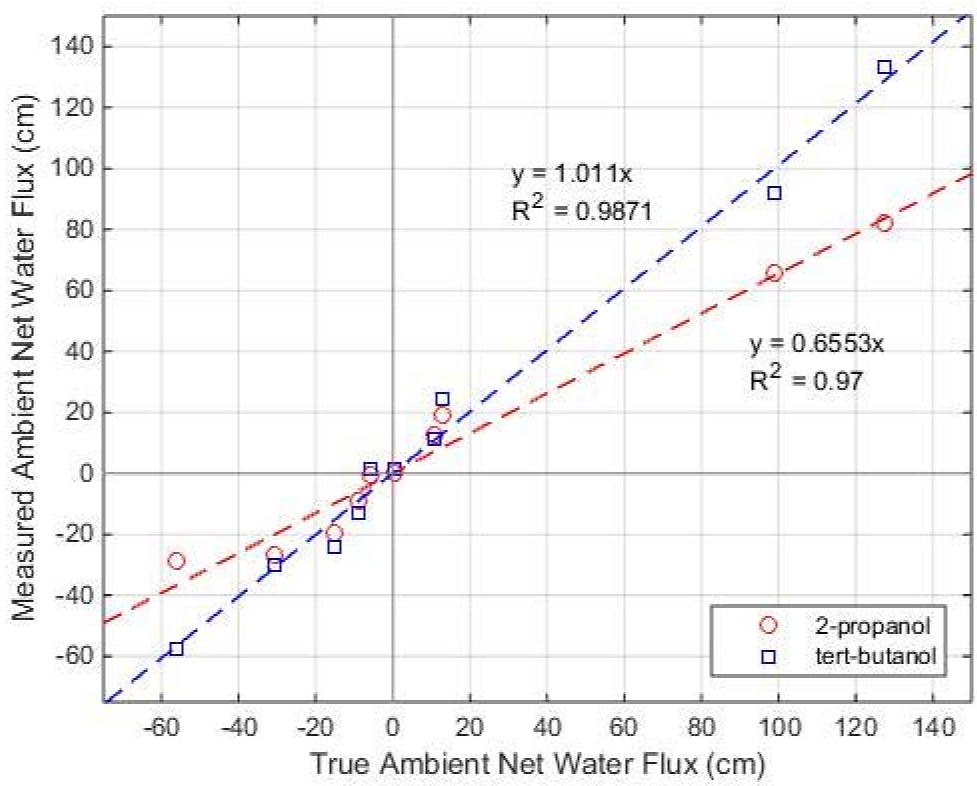

Figure 3. Measured versus true ambient net water fluxes for tracers 2-propanol and tert-butanol.

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Development and Evaluation of Data Accuracy Assessment Algorithms for Identifying Anomalies in Hydro-meteorological Data (Phase I: Stage)

Basic Information

Title:	Development and Evaluation of Data Accuracy Assessment Algorithms for Identifying Anomalies in Hydro-meteorological Data (Phase I: Stage)
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End Date:	2/28/2015
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Descriptors:	None
Principal Investigators:	Ramesh S Teegavarapu

Publications

1. Teegavarapu, Ramesh S.V., Aneesh Goly, and Jayantha Obeysekera. 2013. Influences of Atlantic Multidecadal Oscillation (AMO) Phases on Precipitation Extremes Journal of Hydrology, 2013. doi: 10.1016/j.jhydrol.2013.05.003.
2. Aneesh Goly and Ramesh S.V. Teegavarapu. 2014. Individual and Coupled Influences of AMO and ENSO on regional Precipitation Characteristics and Extremes. Water Resources Research. Accepted. doi: 10.1002/2013WR014540
3. Assessment of Influences of Climate Variability on Storm Event Characteristics. Paper presented at the Annual Meeting of EWRI ASCE, Cincinnati OH, 2013. doi: 10.1061/9780784412947.104
4. Selection and Evaluation of Different Spatial Resolutions for Statistical Downscaling of Precipitation. Paper presented at the Annual Meeting of EWRI ASCE, Cincinnati OH, 2013.
5. Assessment of various Statistical Downscaling Methods for Downscaling Precipitation in Florida. Paper presented at the Annual Meeting of EWRI ASCE, Cincinnati OH, 2013. doi: 10.1061/9780784412947.105
6. Statistical Characterization and Assessment of Precipitation Extremes during Different Phases of Multi-year and Multi-decadal Climatic Oscillations. Paper presented at the Annual Meeting of EWRI ASCE, Cincinnati OH, 2013.
7. Multi-Objective Optimization Methods for Bias Correction of Statistically Downscaled Precipitation. Paper presented at the Annual Meeting of EWRI ASCE, Cincinnati OH, 2013. doi: 10.1061/9780784412947.116
8. Ramesh, S. V. Teegavarapu, Tadasse Meskele, Chandra Pathak. 2012. Geo-Spatial Grid-based Transformation of Multi-Sensor Precipitation using Spatial Interpolation Methods. Computers and Geosciences. Volume 40, March 2012, pp. 28-39. http://dx.doi.org/10.1016/j.cageo.2011.07.004.
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495, July 2013, pp. 74-93. http://dx.doi.org/10.1016/j.jhydrol.2013.05.003

10. Ramesh S. V. Teegavarapu, Missing Precipitation Data Estimation using Optimal Proximity Metric-based Imputation, Nearest Neighbor Classification and Cluster-based Interpolation Methods, Hydrological Sciences Journal, 2013. DOI:10.1080/02626667.2013.862334.
11. Ramesh S. V. Teegavarapu, Climate Change-Sensitive Hydrologic Design under Uncertain Future Precipitation Extremes, Water Resources Research, 49(11), 7804-7814, 2013.
12. Ramesh S. V. Teegavarapu, Statistical Corrections of Spatially Interpolated Precipitation Estimates, Hydrological processes, 2013. DOI: 10.1002/hyp.9906.

Development and Evaluation of Data Accuracy Assessment Algorithms for Identifying Anomalies in Hydro-Meteorological Data (Phase II: Stage)

7/8/2015

Final Report

Developed for:
USGS 104B Grant
WRRC, University of Florida

USGS 104B Grant Project Contract: Dr. Mark Newman

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Executive Summary

The report provides details of the work completed for phase II of the project "Development and Evaluation of Data Accuracy Assessment Algorithms for Identifying Anomalies in Hydro-Meteorological Data". The project is supported by SFWMD and USGS 104B grants. Scope of the work, deliverables and the associated tasks are briefly explained initially and review of different issues related to application of methods identified in the earlier study is also provided. The proof-of-concept developed in the earlier study (phase I) was revised and improved to develop a complete data anomaly and outlier identification tool referred to as hydrologic data evaluation tool (HDET). Details of the development of HDET, description of different modules along with functionalities of each module are provided in this document. The tool that has been developed works in standalone and database connectivity modes. In latter mode the tool interacts directly with District database files. The overall tool design, features and menu and module structure and development was possible by extensive input and feedback from the project team from the District. Stage data assessment based on observations from six sites in the SFWMD region using HDET is also included in this report. Based on the assessment, different methods were ranked using an aggregated performance measure. Extensive evaluation of the tool for more number of sites is planned in future. The executable software and the source code of the tool were provided to the District.

Keywords: stage, data anomalies, hydro-data management, statistical methods, cluster and rule-based methods, Stage Data Evaluation Tool (HDET), MATLAB.

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Acknowledgments

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1. Introduction and background

Acquisition of hydrologic and hydraulic data is the key component of water resources management in central and south Florida. The District is responsible for the collection, validation, and archiving of the District's hydrologic data. The types of data include rainfall, evaporation, water levels (stage), water control structure (gate and pump) operations, and flow. The District requires accurate data collection, processing and archiving of these data. There is a constant need for good quality hydrometerologic data for operations of large canal network. In early 2013, the Hydro Data Management (HDM) at SFWMD initiated an effort to review and evaluate different data accuracy assessment algorithms for development of a prototype tool for identifying the anomalies in stage data. In the completed first phase of study a prototype tool, Hydrologic Data Evaluation Tool (HDET) was developed. The second phase of this continuing project build on the prior work from phase I and worked towards several improvements and testing of the HDET.

2. Objectives

The main objectives of the second phase of the continuing study started in 2013 have focused on:

- Work on improvements of the prototype menu structure and few tool components and also enhancements of the same with the addition of any new assessment methods and exhaustive evaluation of the tool.
- Development and implementation of neighborhood value-based approach to analyze a single data value using a group of consecutive time series values, as well as to improve the spatial neighborhood approach to analyze a single data value using correlated time series values of known/related data sets.
- Testing of the HDET tool after the enhancements are made using several different performance measures.

3. Scope of Work

The scope of work involved the following tasks:

- Extensive data gathering of existing literature relating to neighborhood value-based and spatial neighborhood approaches.
- Incorporation of these approaches in the HDET tool and enhancements of the tool in different modules.
- Identification and ranking of all the algorithms by incorporating new performance measures that could be used to detect surface water level stage data anomalies and determine data accuracy.
- Testing of the enhanced HDET environment for evaluating surface water level stage data accuracy algorithms.

4. Serial and Parallel Approaches

Serial and parallel executions of multiple methods were evaluated to identify anomalies and outliers in stage data. In case of serial processing of stage data for anomalies and outliers (shown in Figure 1), the length of data (i.e. number of temporal observations) may be reduced from initial length (step 0). When outliers and anomalous observations are eliminated, data length from step 0 to future steps is reduced when a series of methods are applied for outlier and anomaly detection. The order in which the methods are applied may or may not influence the overall performance of the specific combination of methods chosen. The applicability of a specific method may or may not be affected by data reduction (due to removal of outliers and anomalies) caused due to use of a specific method preceding to the current one. Judicious selection of sequence of methods is required.

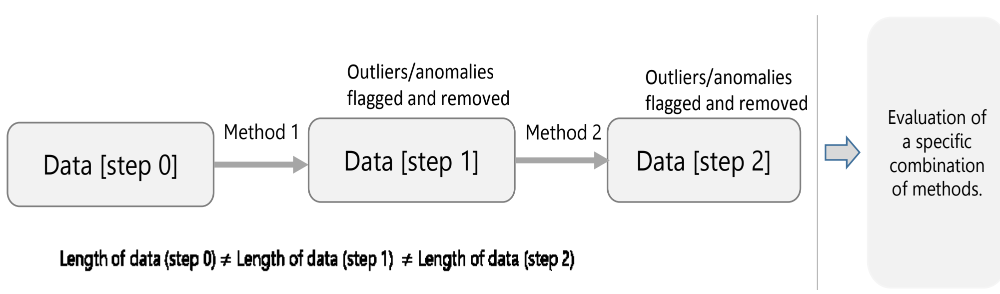


Figure 1 Schematic showing serial execution of multiple anomaly and outlier detection methods.

In case of parallel processing of stage data for anomalies and outliers as shown in Figure 2, the length of the data (i.e. number of temporal observations) will not be reduced from initial length (step 0) and same data is used for all the methods. Outliers and anomalies are only flagged and no data length reduction from step 0 to future steps is possible in parallel approach. In theory, the approach is parallel evaluation of data using different methods. However, in practice (execution of methods using the tool or with computation on a single computer) will still be serial. Order in which the methods are applied will not influence the overall performance of the specific combination of methods chosen. The applicability of any specific method will not be affected by the use of a specific method preceding to the current one. Considering the advantages of this approach, parallel execution of methods is adopted in HDET.

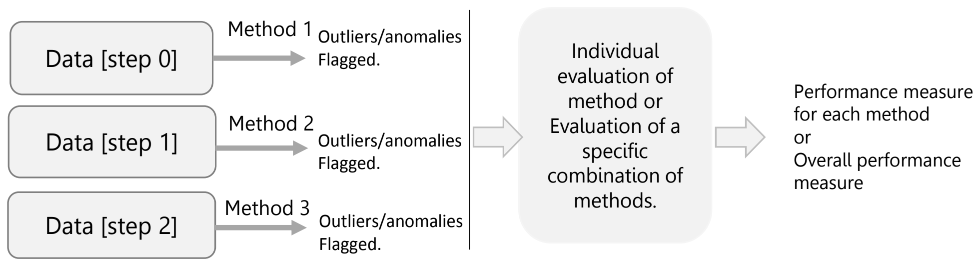


Figure 2 Schematic showing parallel execution of multiple anomaly and outlier detection methods.

5. Neighborhood-based Method

Neighborhood approach relies on observations from nearby site (referred to as reference site in this study) to identify anomalies in observations at base site (i.e. a site at which the observations need to be evaluated).

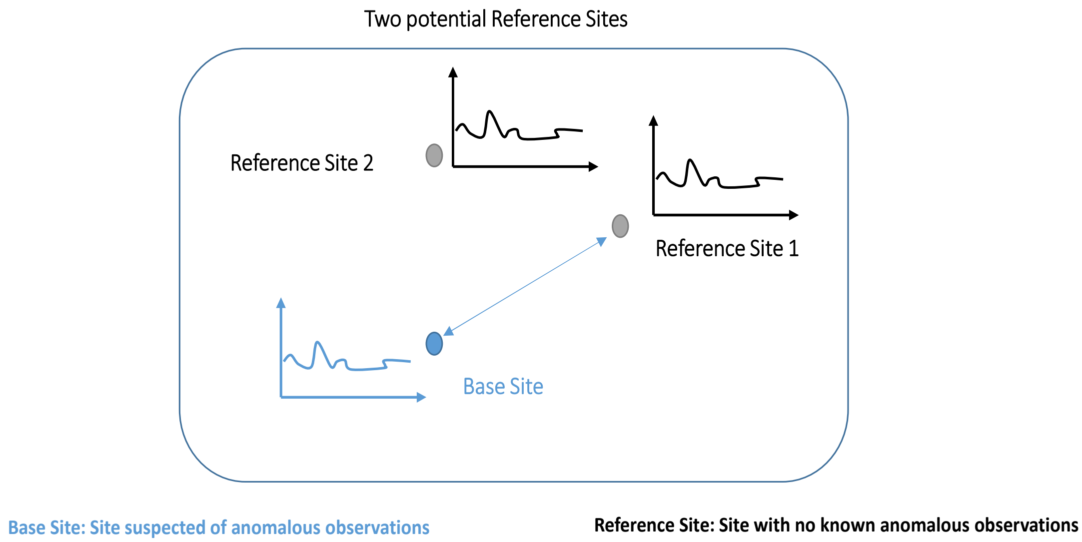


Figure 3 Schematic showing the use of data from two near-by sites for neighborhood-based approach.

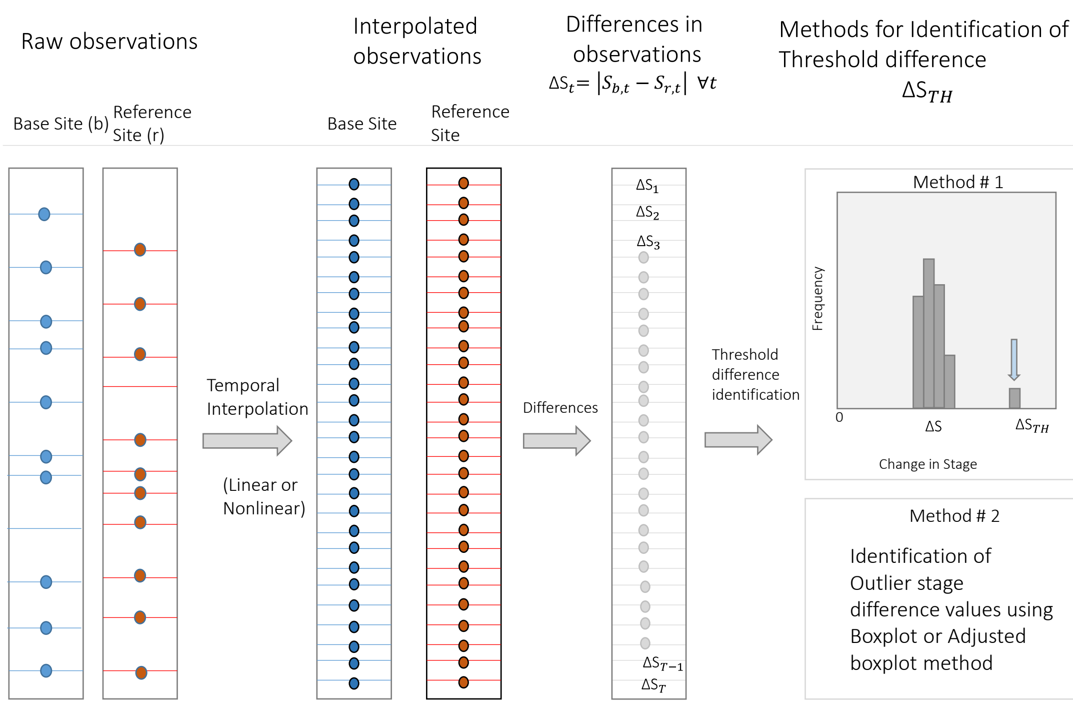
The nearest neighbor method added to the existing suite of methods that are being tested for stage data anomaly and outlier detection. Reliable reference sites without any known issues with sensors are used in the application of this method. Neighborhood station (i.e., reference site) was selected in this study by selecting one of the stations that is near to the base station. A list of stations near to a set of base stations was provided by SFWMD.

5.1. Anomaly and Outlier Identification using Neighborhood Approach

Once time consistent series are established for base and reference sites, a threshold difference value between two observations for a given time interval is obtained to determine the anomalies. Time consistent observations are obtained by the following steps:

1. Identify the smallest time interval length from observations from two sites (i.e., base and reference sites).
2. Use these time intervals from step 1and interpolate using "linear or nonlinear interpolation" for both base and reference sites.

Once Interpolation is completed both base and reference sites will have exactly same number of time intervals (and observations)



T: total number of time consistent stage observations, $S_{b,t}$: Stage observation at base site in time interval t; $S_{r,t}$: stage observation at reference site

Figure 4 Identification of anomalies and outliers using neighborhood method.

Steps used for the approach as shown in Figure 6 include: 1) Obtain the difference between stage measurements between base and reference sites; 2) Evaluate the distribution of absolute differences and 3) Identify the "threshold difference" to use as a guidance to identify the anomalies. One check to confirm that the method is appropriate will involve assessment of correlation between two data sets after suspicious observations are removed from both the sites.

5.2. Anomalous observation Identification at base and reference sites.

Anomalous observations can be identified if there is any discrepancy in the observations at two sites. If there discrepancy exists then both the observations in that interval are assigned flags. Since "Base site" is of interest, only base site observations with flags are taken to next step. In the next step, the flags that are defined for constant length time intervals will be assigned to temporal intervals from which constant length time intervals are derived. A threshold value based on the differences in stage values between base and reference site is initially established based on procedure discussed in the previous section.

Using the ΔS_{TH} the following steps are carried out:

1. For a given time interval, t, If $\Delta S_t > \Delta S_{TH}$ then $S_{b,t}$ and $S_{r,t}$ are flagged as anomalous stage observations.
2. If $\Delta S_t < \Delta S_{TH}$ then $S_{b,t}$ and $S_{r,t}$ (stage values) are retained without any flags.
3. Execute step 1 for all the observations.

When flagged observations at both sites are removed, the correlation coefficient based on the remaining observations at two sites is evaluated. If the correlation improves, then it is highly likely that anomalous observations are correctly identified.

5.3. Assignment of flags for raw observations at base site

Transferring anomalous observation-based flags from time consistent observations to the stage time series at base site requires flagging all the observations at the base site with time intervals that are close to the time intervals associated with flagged values from time consistent observations (obtained from steps 1 and 2 defined in the Section 5.2).

6. Identification of Structure and Sensor Limits from Past Data

Physical limits of structure cannot be established by available stage data alone. Long-term historical data if available can be used to deduce information about these limits. Data about these limits from the monitoring agency is always beneficial. Sensor limits can be obtained from the agency with the help of field operations staff. These limits can be established from monitoring data but may not be always accurate. Possible changes to sensors (type and other specifications) may change these limits over time.

Sensor measurement limits can be established using the following steps:

1. Obtain the minimum and maximum values of the observations for these flat lines (i.e., constant data values). These flat lines can be temporary and may be possibly due to failure of the sensor to record values above or below a specific measurement level.
2. Check if no other values above this limit exist or not.
3. If values above or below these limits exist, check these values to say if the sensor has recorded them in a sequence.

4. If a sequence of minimum and maximum values exist (above and below flat line), then these can be regarded as the sensor measurement limits.

7. Identification of Flat Line Anomalies

In the identification of constant data anomalies (also known as 'flat lines' shown in Figure 5), two issues need to be considered: 1) number of observations with in a time period that have constant values to be marked as anomalies and 2) threshold time period.

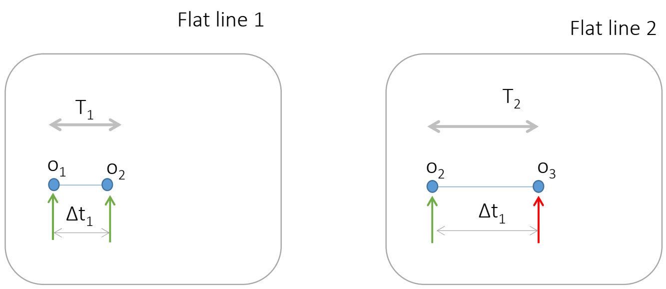


Figure 5 Examples of two constant anomalies (flat lines).

Methodology

If two consecutive observations have same values, the segments with these consecutive observations were initially isolated from the time series. Rules relating to application of threshold time period were applied and they are:

1. All flat line period segments in the entire stage time series are identified with a threshold time period equal to two consecutive time intervals (T_c).

2. For an identified flat line segment, time intervals between observations are obtained.

3. These time intervals are then checked against a pre-fixed threshold (ΔTh) to determine if the observations need to be flagged as anomalous observations. The value of ΔTh can be user specified or a site-specific can be determined.

8. Rate of Change

Sudden changes (increases or decreases) as shown in Figure 6 in consecutive measurements are potential cases for outlier/anomalous measurements. The rate of change was evaluated in such cases.

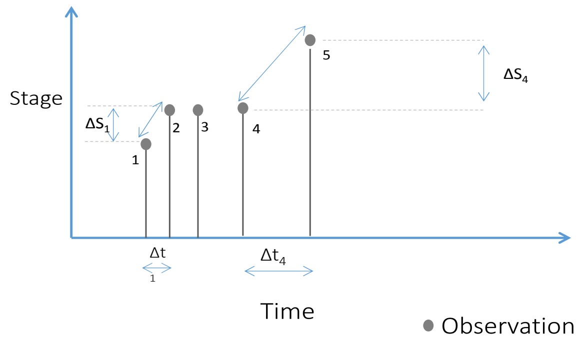


Figure 6 Examples of rate of change calculations.

Rate of change (RC) = ΔS/Δt (change in stage value based on any two consecutive observations over time elapsed between those observations). A threshold value of RC referred to as RC_{TH} value can be specified by the user as a site- specific parameter or derived from the available time series. Selecting the best RC_{TH} value from experiential knowledge and expertise is recommended.

Two possible ways to obtain the threshold value (RC_{TH}) are:

1. Obtain RC_{TH} value that is site-specific from an expert.
2. Obtain RC value based on stage data that has gone through the QAQC and deemed anomaly or outlier free. The largest value of RC is the threshold value.

The best value of RC_{TH} can also be obtained from available historical data. All the RC values for a time series which is not affected by sensor change or any changes to site conditions are initially calculated. Then a 95% percentile value of all RC values is used as a threshold value (RC_{TH}) to identify anomalous observations. In the current study this approach was adopted.

8.1Anomalous observation Identification

Using the RC_{TH} possible anomalous observations are obtained using the following steps:

1. Calculate RC_t using ΔS_t from observations O_t and O_{t+1} and Δt_t
2. For a given time interval, t, If $RC_t > RC_{TH}$, then O_{t+1} is flagged as anomalous stage observation
3. Execute steps 1 and 2 for all the observations.

9. Assignment of Flags for Anomalies and Outliers

Provisional and archived (expert) datasets are used to evaluate HDET. Currently, observations with exactly same time stamp are filtered from both provisional and archived datasets. This helps in having time consistent data sets to evaluate the performance of HDET using contingency measures. In many instances, it has been noted that data have been added or deleted from the provisional data when it was reviewed by an expert at SFWMD. Data that were added or deleted were not always flagged. Two methods were evaluated in this study to address this situation and are described below.

Method # 1.

In this method as shown in Figure 7, time consistent observations from both provisional and archived datasets are used. Time stamps of provisional data as are used as a reference. Observations added by expert are removed and flags for observations removed by expert are retained. This method is appropriate if the number of data added is less than a specific (threshold) percentage of data.

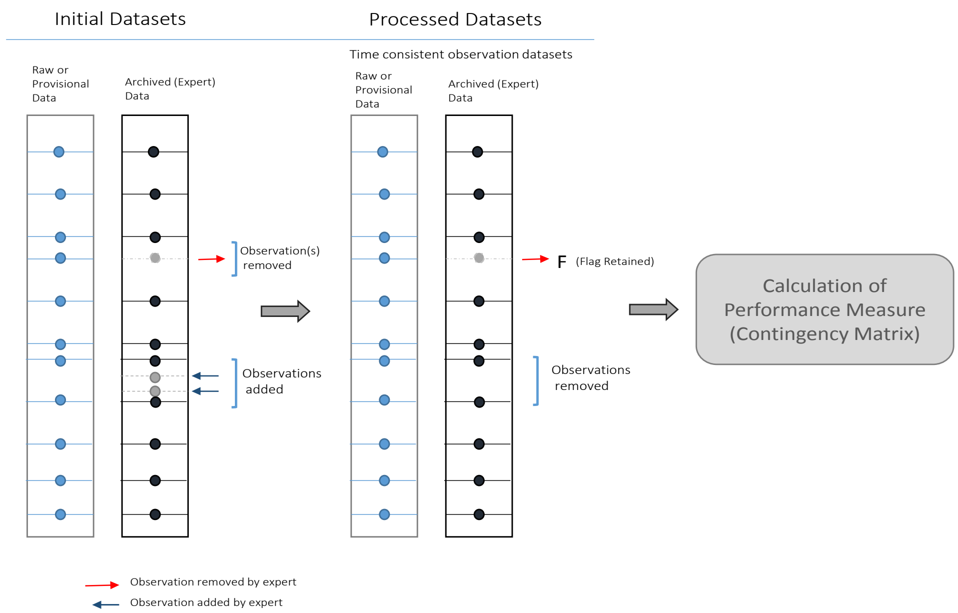


Figure 7 Assignment of anomalies and outliers using evaluation method #1.

Method # 2.

In this method as shown in Figure 8, a check is made if all the added and deleted data have flags. If no flags exist, then flags are then added. The expert dataset is then used as a basis and data in the provisional dataset is obtained by linear or nonlinear interpolation for all time intervals in which data has been added. This step generates time consistent observations for provisional and expert data.

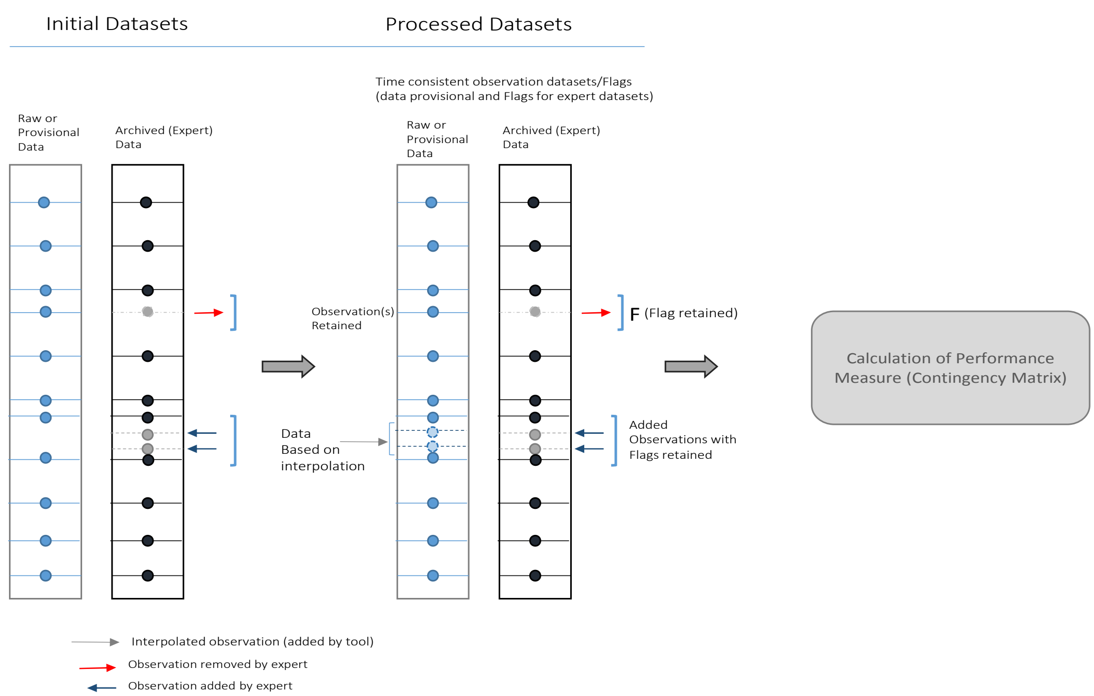


Figure 8 Identification of anomalies and outliers using evaluation method #2.

10. Finalization of Anomalies and Outliers from Single and Multiple Methods

HDET allows users to executive one or more methods to evaluate anomalous data. When only one method is selected by the user, all the anomalies/outliers identified are flagged and are used for calculation of performance measure(s). When multiple methods are selected and the methods are executed in parallel then different selection methods referred to as S1, S2 and S3 shown in Figure 9 and listed below can be used for identifying the final set of outliers/anomalies.

- S1: An observation is flagged if at least one method identifies it to be an outlier/anomaly.
- S2: An observation is flagged if more than one method identifies it to be an outlier/anomaly.
- S3: An observation is flagged if all the methods identify it to be an outlier/anomaly.

The selection method S3 is the strictest selection method of all the three and may lead it to lowest number of final set of outliers/anomalies. Each run constitutes execution (in parallel) of one or more methods selected by the user. After anomalies/outliers are identified by using one or more selection methods, the number of “true positive values” is used to derive rank for each run. In the current study method S1 is used.

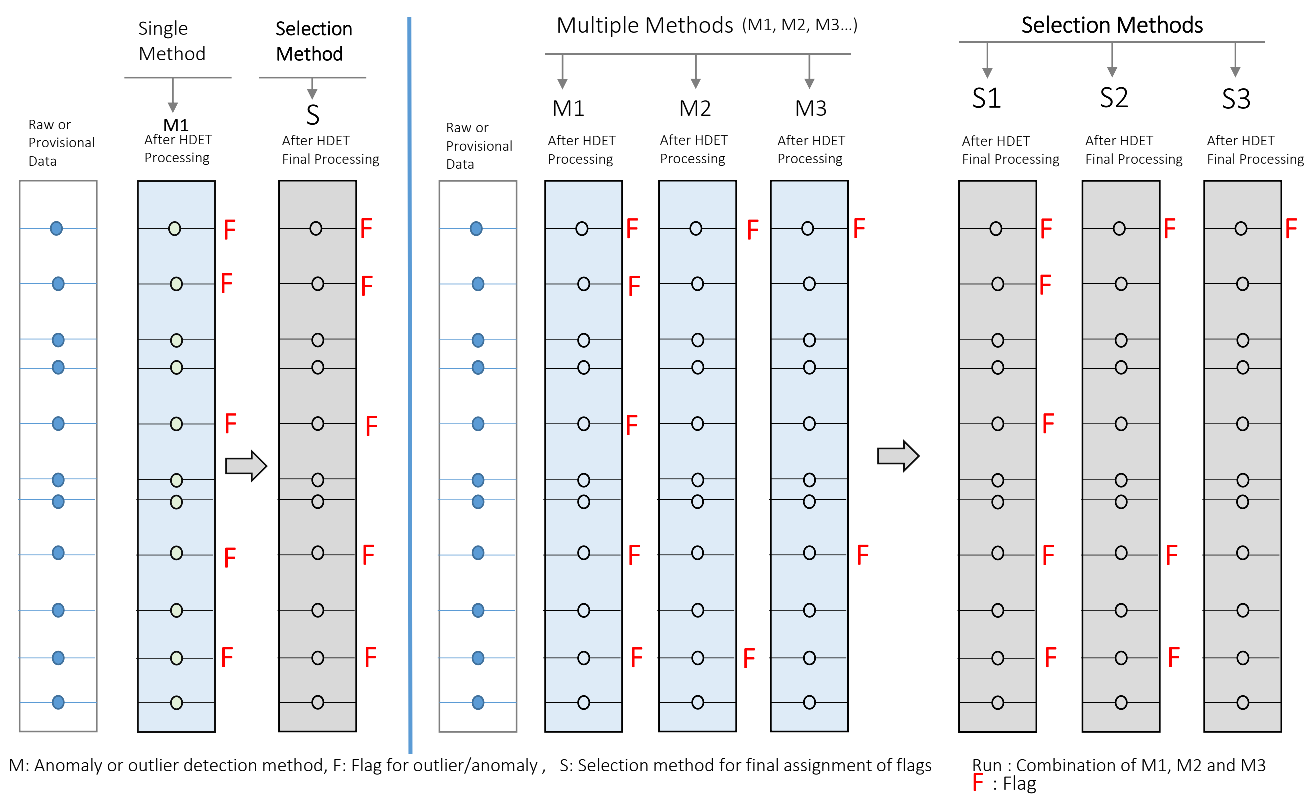


Figure 9 Identification of anomalies and outliers using single and multiple selection methods.

11. Architecture of the Prototype Environment

HDET provides a select suite of data accuracy assessment algorithms in a prototype test environment that can be used by the SFWMD for detection of anomalies in stage data. The prototype environment allows the user to utilize the system at three different temporal levels: (1) historical (time greater than two days and up to two weeks); (2) near real-time (i.e., time greater than one day and up to two days) and (3) real-time (i.e., time less than a day). The methods are ranked based on results from a 2 x 2 contingency table. HDET evaluates potential outliers in stage data with the binary results (yes or no) from all the methods tested in this study. The test environment developed is generic in nature and can be expanded in its functionality in future to detect anomalies in other hydrological variable datasets such as precipitation and others. The test environment is expected to be functional in future for real-time application.

12. Evaluation of Anomaly and Outlier Detection Techniques

Evaluation of the anomaly detection methods is critical when multiple methods/techniques are used in a run or multiple runs are used. Contingency and performance measures are developed in the phase I of this study. Results were obtained from the anomaly detection method for each time series value of stage and from an independent expert identifying anomalies. These results from two sources are evaluated using the contingency table. The probability of detection (POD), also known as the hit rate, measures the fraction of anomalies detected by the method that was correctly detected by the expert and error measure is used in HDET to rank the runs. A run constitutes execution of one method or a set of methods.

13. General Observations

If substantial number of observations is not added to the archived data by expert, then processing archived data by removing added observations to obtain time consistent observations is recommended. Influence of this removal on evaluation of methods of HDET is negligible. If the number of observations that are added to archived data is substantial (above a specific threshold number), then provisional data should be augmented with additional data using interpolation methods. The threshold number should be pre-defined. Interpolation methods may introduce changes to data and ultimately affect the performance measures. The selection method S1 is preferred over other two as it uses less strict criterion to identify outliers/anomalies compared to other two methods. Once observations are flagged using a specific selection method, contingency matrix and a combined performance measure is used to rank the runs and the best run based on this aggregated measure can be selected.

14. Tool Development and Features

The Hydrologic Data Evaluation Tool (HDET) was developed using MATLAB environment with a capability to interact with the District's databases with hydrometeorological data. Initially the tool was developed to read data in a flat file (ASCII text file) format and later the ability to interact with the databases and query data depending on the user needs was developed. The tool architecture is modular in nature and each module can be independently modified or revised according to the District's requirements. The initial screen of the tool is shown in the Figure 10. The main menu provides access to five different modules excluding the help. Different modules perform different functions.

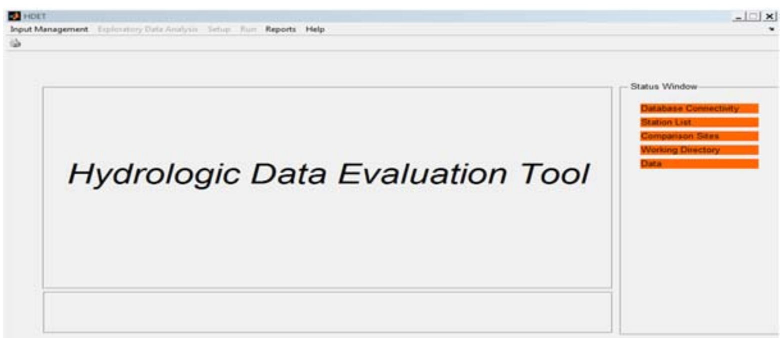


Figure 10. A screenshot of initial menu of HDET

Details of the tool execution and installation of the tool on Microsoft Windows-based platform is provided in a separate document (i.e., Help Manual for HDET). Immediately after the execution, the tool checks for connectivity to District database. If connection is established, the highlighted color of "Database Connectivity" in the status window will be changed from orange to green. This connectivity will be help the tool to access, retrieve and write to District's database files.

15. Architecture of HDET

The architecture of HDET source code and general layout of the different modules along with their connectivity to graphical interface elements and functions is shown in the Figure 11. The architecture is flexible and additional user interfaces can be easily developed to further improve the ease of use of the tool. More details of this architecture are provided in a separate help document.

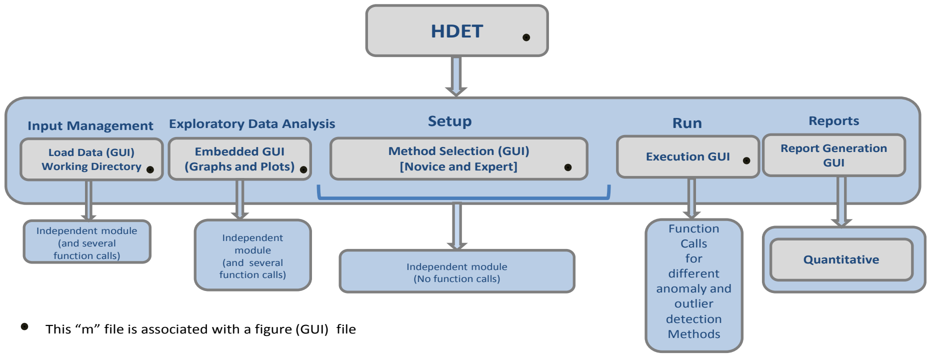


Figure 11. Architecture of HDET source code (developed in MATLAB).

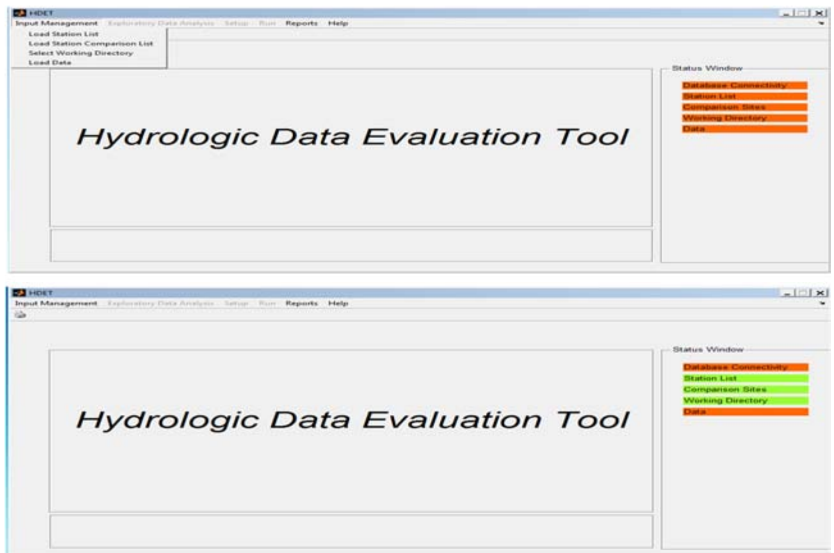


Figure 12. Screenshot of the HDET module showing completion of several tasks from the status window.

Three different tables from SFWMD database as shown in the Figure 13 can be accessed using the tool and they include: 1) raw; 2) provisional and 3) comparison site. An interface shown in Figure 13 is used for the access of data through one of these databases. The "Load data" module shown in Figure 13 allows the user to select a specific site based on site/station identification number from pull down menu. Once a station is selected and if the database connectivity is established, the period of record (POR) for different database files is established and user is provided with a list of stations that are potential candidates for comparison or use in the neighborhood approach. In a standalone mode, user need to use POR button to obtain information about the datasets available. Based on all the available datasets, period of record that is common to all is established and user can load the data for further analysis. Archive data is then used for the evaluation of the tool using different performance measures.

Figure 13. A screenshot of the load data module.

16. Exploratory Data Analysis (EDA) Module

The EDA module of HDET is shown in Figure 14. Once the data related to a station (or site), location, structure and sensor limits are obtained, the exploratory data analysis (EDA) module can be used. EDA menu provides insights into the data by providing summary statistics, identifying outliers that are outside of the limits of the structure as well as the sensor. The identified outliers are listed along with date and time of the day at which the anomalies were recorded. A histogram of the time intervals at which stage data are recorded is also provided to the user. This information helps in identifying any inconsistencies in the observation recording times or any long gaps in the observation record.

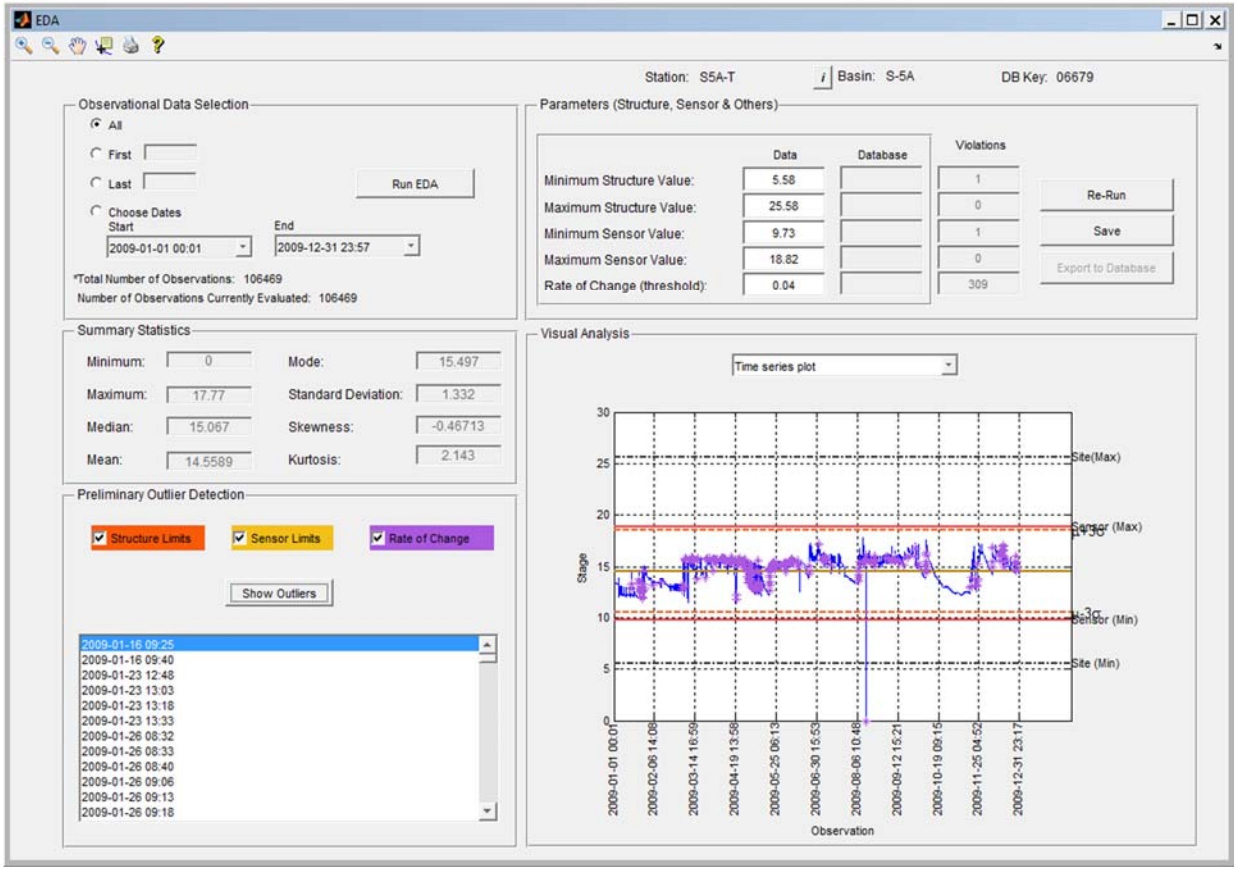


Figure 14. Details of the exploratory data analysis (EDA) module of HDET.

Time distribution of data, histogram of observations, non-exceedance probability plot and also stage exceedance curve are provided to the user for evaluation of the data. Preliminary outlier detection feature lists the number of observations detected and anomalous observations. These observations are highlighted in the time-series graph available under visual analysis section of this module. The data analysis provides a flexible option for the user to select observations between two specific dates, a specific number of observations from the first or the last observation in the period of record. In the time series (in visual analysis section) menu, the selected length of observation period is depicted along with the time interval information.

17. Setup Module

The setup module of HDET as shown in Figure 15 provides a facility to the user to work in two modes: 1) Novice and 2) Expert. When "Novice" mode is chosen, all the methods are executed and the method selection menu is disabled. However, if "Expert" mode is chosen, the user can select up to five runs with any combination of currently available seven methods. Runs beyond five are currently not allowed by the tool.

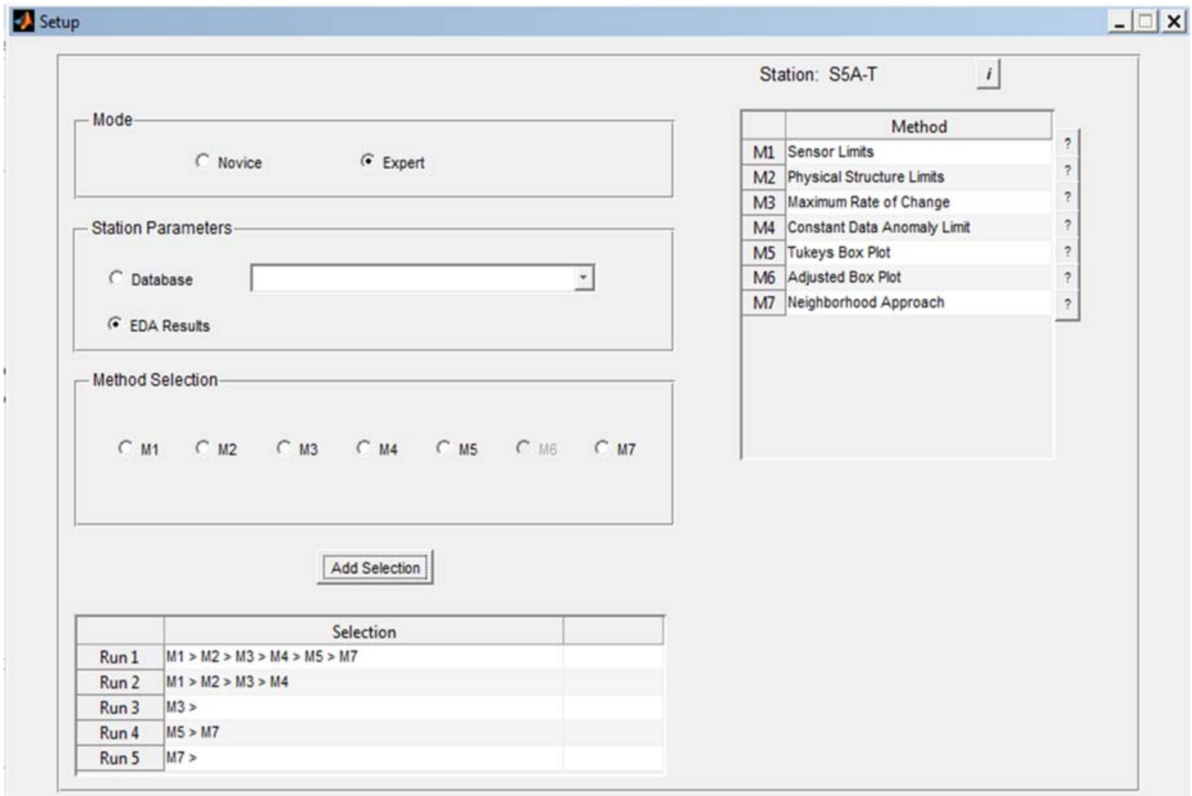


Figure 15. Details of the setup module of HDET.

Once the selection of runs is completed, user will asked to go to "Run" option available from the main menu of HDET. A screenshot of the "Run" module is shown in Figure 16. The execution of runs is completed with progress of each run completed shown in green color.

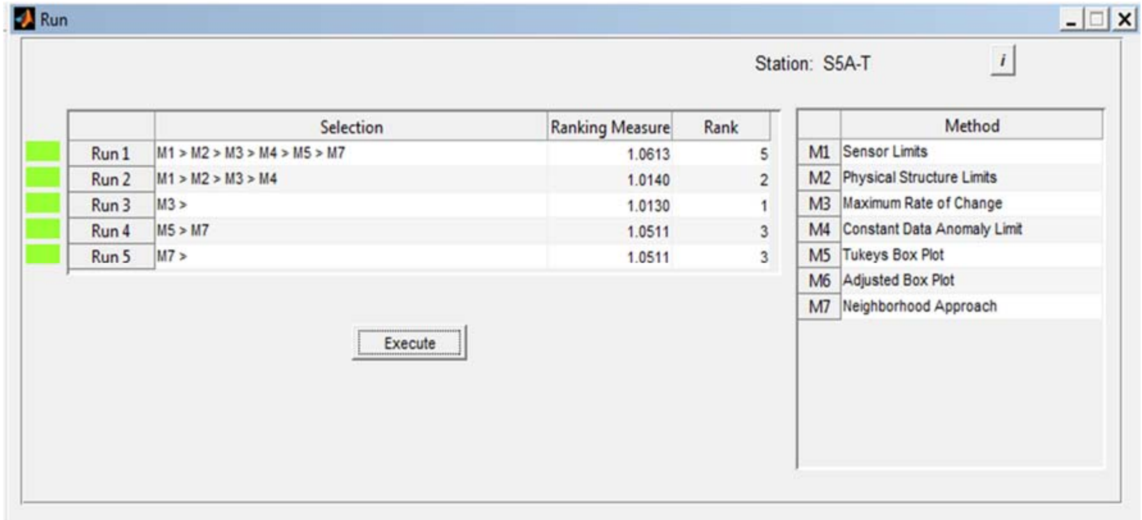


Figure 16. Details of the run module of HDET.

17.1 Performance Measures

A number of contingency measures are available in HDET for user to assess the outlier and anomaly detection methods and assess the performances of one or more methods. In order to evaluate the methods using these measures, two data files are used and they include: 1) stage observations data file evaluated and flagged by HDET and 2) stage observations data file (of same format and similar number of the observations as the former data file) evaluated and flagged by an expert or any other tool. A screenshot of reports module is shown in the Figure 17. This module will help to review the results of HDET evaluations using different runs.

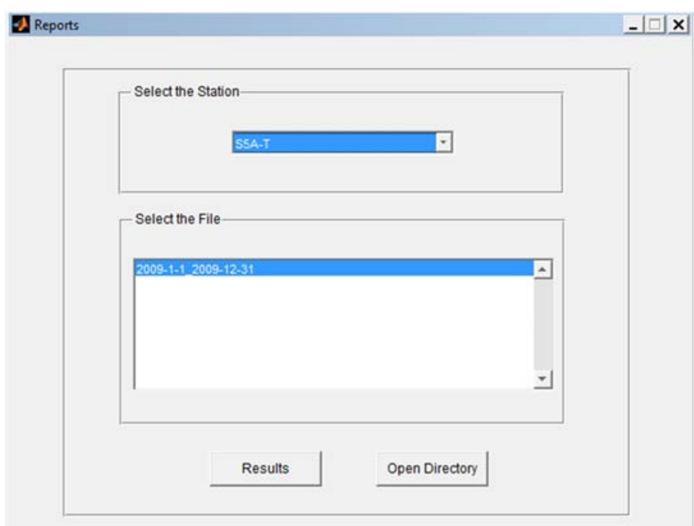


Figure 17. A screenshot of the report module of HDET

18. Application of HDET and Results

Application of HDET to identify anomalous observations will depend on accuracy of information available about: 1) sensor measurement limits and 2) physical structure limits. Stage data from six different observation sites were provided by the District for evaluation of the HDET. Also, for evaluation of the tool, the sensor and well limits based on NGVD29 datum provided by the District are listed in Table 1.

Table 1 Well and sensor limits+ for different stations.

Station ID	Well upper limit(ft.)	Well lower limit (ft.)	Sensor upper limit (ft.)	Sensor lower limit(ft.)
S5A-H	19.92	2.32	12.36	7.50
S5A-T	25.58	5.58	18.82	9.73
S5AE-H	25.06	10.50	19.50	10.50
S6-H	32.20	5.70	13.00	7.59
S6-T	32.21	4.70	18.27	8.00
S65D+H	32.83	19.73	28.31	25.34

In feet, Datum: NGVD29

Performance evaluation of the methods was completed using the stage data that is flagged by the HDET and also a dataset with outliers identified by an expert at SFWMD. Comparison of these files using the performance evaluation module generates the contingency measures required to evaluate different rule-based, statistical and hybrid methods. Few data format related issues were resolved to obtain a perfect match between the observations that are flagged by the tool and those provided after expert evaluation. The performance evaluation module is thoroughly tested using 5 runs for each site with one or more methods listed in Table 2. Ranking of runs for six sites are provided in Table 3.

Table 2 Method or combinations of methods used for evaluation of HDET.

Method ID	Method or combinations of methods
M1	Sensor limit-based rules
M2	Structure limit-based rules
M3	Constant data anomaly
M4	Rate of Change
M5	Tukey's Box Plot
M6	Adjusted Box Plot
M7	Neighborhood Approach

All the methods listed in Table 6 are applied to assess outliers and anomalies from stage data for a period of one year (1/1/2009 -12/31/2009) at all the six sites previously indicated. The ranking of the methods was based an aggregate performance measure based on probability of detection and error measure. Results from contingency measures are also provided by HDET for evaluation. Ideally for any method, values from positive-negative and negative-positive counts should be zero or low. A high number of negative-negative results in contingency table counts indicate that both the tool and the expert have not flagged those observations as outliers or anomalies. At three of the six stations, use of four or five methods resulted in the best ranking. The rankings of runs were different for different stations and no uniformity in top ranking methods is observed. It is important note that the rate of change is obtained from the data and has the largest influence on the identification of outliers. Method M6 was not used for the current datasets in different runs. The method based on adjusted box-plot approach currently has limitations in dealing with large datasets.

A sensitivity analysis based on different values of threshold rate of change indicated that use of a lower value below 0.02 resulted in more number of observations being flagged by the HDET. Changes in the threshold value affected the results of the performance measures and the rankings. An immediate future task is to evaluate a number of methods with several different combinations at a variety of sites to arrive at the best possible combination of rule-based and statistical methods. Results and analysis of performance measures for different runs and sensitivity analysis of rate of change threshold parameter are presented in Appendix A.

Table 3 Ranking of different runs obtained from evaluation of different methods using HDET.

Station	Run (with one or more methods)	Rank
S5A-H	M1 , M2 , M3 , M4 , M5 , M7	5
	M1 , M2 , M3 , M4	2
	M3	1
	M5 , M7	3
	M7	4
S5A-T	M1 , M2 , M3 , M4 , M5 , M7	5
	M1 , M2 , M3 , M4	2
	M3	1
	M5 , M7	3
	M7	4
S5AE-H	M1 , M2 , M3 , M4 , M5 , M7	1
	M1 , M2 , M3 , M4	2
	M3	3
	M5 , M7	4
	M7	5
S6-H	M1 , M2 , M3 , M4 , M5 , M7	5
	M1 , M2 , M3 , M4	2
	M3	1
	M5 , M7	3
	M7	4
S6-T	M1 , M2 , M3 , M4 , M5 , M7	4
	M1 , M2 , M3 , M4	1
	M3	2
	M5 , M7	5
	M7	3
S6D+H	M1 , M2 , M3 , M4 , M5 , M7	4
	M1 , M2 , M3 , M4	1
	M3	2
	M5 , M7	5
	M7	3

19. Conclusions

This report provided details of the work completed for the project dealing with the "Development and Evaluation of Data Accuracy Assessment Algorithms for Identifying Anomalies in Hydro-Meteorological Data (Phase II: Stage)". This report is one of the final deliverables that provided details of the hydrologic data evaluation tool (HDET) developed during course of this study. Major modifications made to the prototype environment developed in the previous study (phase I) are reported in this document. The report also provided technical details and discussed implementation issues related to several data anomaly detection methods that were evaluated. Different modules of HDET developed in this project is described and results from evaluations of stage data at six sites provided by the District are reported.

APPENDIX A

The HDET tool is evaluated using data at six sites provided by the SFWMD. Based on the number of methods several combinations of methods are possible depending on the number of methods selected at a time. Parallel execution of methods is used in HDET. Therefore, only unique combinations of these methods need to be evaluated. A total of 127 combinations need to be evaluated. However, in this phase of the study only a few combinations of methods that constitute as different runs are tested. Table 4 provides a list of unique combinations of methods possible depending on the number of methods (from a maximum number of seven) selected by the user.

Table 4 Unique combinations of methods possible based on the number of methods selected.

Number of methods selected by user	Unique Combinations of methods
1	7
2	21
3	35
4	35
5	21
6	7
7	1

HDET was evaluated using a number of contingency measures for each station. A total of 6 sites were evaluated with five of the six stations having observations over 75,000 for the period of record. The structure and sensor limits were provided by the District are used in HDET and only one parameter (maximum rate of change threshold) is estimated from the stage data. Contingency matrices calculated based on the observations at all sites are in Tables 5 -10.

Table 5 Contingency measures calculated based on HDET evaluation results for station S5AE-H.

Contingency Measure\Run	1	2	3	4	5
Positive(p)-Positive(E)	8	5	2	6	6
Positive(p)-Negative(E)	3373	2057	1359	1420	809
Negative(P)-Positive(E)	7	10	13	9	9
Negative(P)-Negative(E)	22859	24175	24873	24812	25423
Concordance	0.871	0.921	0.948	0.946	0.969
Error Rate	0.129	0.079	0.052	0.054	0.031
Sensitivity	0.002	0.002	0.001	0.004	0.007
Specificity	1	1	0.999	1	1
Probability of Detection	0.533	0.333	0.133	0.4	0.4
Probability of False Detection	0.129	0.078	0.052	0.054	0.031
Rank	1	4	5	3	2

Table 6 Contingency measures calculated based on HDET evaluation results for station S5A-H.

Contingency Measure\Run	1	2	3	4	5
Positive(p)-Positive(E)	0	0	0	0	0
Positive(p)-Negative(E)	5863	1052	965	5334	5334
Negative(P)-Positive(E)	2	2	2	2	2
Negative(P)-Negative(E)	100584	105395	105482	101113	101113
Concordance	0.945	0.99	0.991	0.95	0.95
Error Rate	0.055	0.01	0.009	0.05	0.05
Sensitivity	0	0	0	0	0
Specificity	1	1	1	1	1
Probability of Detection	0	0	0	0	0
Probability of False Detection	0.055	0.01	0.009	0.05	0.05
Rank	5	2	1	3	4

Table 7 Contingency measures calculated based on HDET evaluation results for station S5A-H.

Contingency Measure\Run	1	2	3	4	5
Positive(p)-Positive(E)	0	0	0	0	0
Positive(p)-Negative(E)	5863	1052	965	5334	5334
Negative(P)-Positive(E)	2	2	2	2	2
Negative(P)-Negative(E)	100584	105395	105482	101113	101113
Concordance	0.945	0.99	0.991	0.95	0.95
Error Rate	0.055	0.01	0.009	0.05	0.05
Sensitivity	0	0	0	0	0
Specificity	1	1	1	1	1
Probability of Detection	0	0	0	0	0
Probability of False Detection	0.055	0.01	0.009	0.05	0.05
Rank	5	2	1	3	4

Table 8 Contingency measures calculated based on HDET evaluation results for station S6D+H.

Contingency Measure\Run	1	2	3	4	5
Positive(p)-Positive(E)	836	806	292	34	34
Positive(p)-Negative(E)	13299	6990	3486	6710	3906
Negative(P)-Positive(E)	7908	7938	8452	8710	8710
Negative(P)-Negative(E)	65891	72200	75704	72480	75284
Concordance	0.759	0.83	0.864	0.825	0.857
Error Rate	0.241	0.17	0.136	0.175	0.143
Sensitivity	0.059	0.103	0.077	0.005	0.009
Specificity	0.893	0.901	0.9	0.893	0.896
Probability of Detection	0.096	0.092	0.033	0.004	0.004
Probability of False Detection	0.168	0.088	0.044	0.085	0.049
Rank	4	1	2	5	3

Table 9 Contingency measures calculated based on HDET evaluation results for station S6H.

Contingency Measure\Run	1	2	3	4	5
Positive(p)-Positive(E)	0	0	0	0	0
Positive(p)-Negative(E)	6154	1094	964	5126	5126
Negative(P)-Positive(E)	4	4	4	4	4
Negative(P)-Negative(E)	97618	102678	102808	98646	98646
Concordance	0.941	0.989	0.991	0.951	0.951
Error Rate	0.059	0.011	0.009	0.049	0.049
Sensitivity	0	0	0	0	0
Specificity	1	1	1	1	1
Probability of Detection	0	0	0	0	0
Probability of False Detection	0.059	0.011	0.009	0.049	0.049
Rank	5	2	1	3	4

In the initial HDET evaluation process only 6 methods were used. The adjusted Boxplot method was not evaluated as it involved calculations with large matrices. The rate of change threshold value is the most influential parameter that affects the results and rankings of HDET. This can be easily evaluated when EDA module is used in HDET and the number of violations is assessed. In general when this parameter is increased, the number of violations are reduced. However, additional analysis need to be conducted to identify the best value of this parameter for each site. In general, the tool is able to identify the anomalies and outliers with good success. This conclusion is based on limited number of runs experimented and results reported in Tables 5-10.

Table 10 Contingency measures calculated based on HDET evaluation results for station S6-T.

Contingency Measure\Run	1	2	3	4	5
Positive(p)-Positive(E)	30	21	19	14	14
Positive(p)-Negative(E)	6349	827	683	5604	4941
Negative(P)-Positive(E)	1349	1358	1360	1365	1365
Negative(P)-Negative(E)	91722	97244	97388	92467	93130
Concordance	0.923	0.978	0.979	0.93	0.937
Error Rate	0.077	0.022	0.021	0.07	0.063
Sensitivity	0.005	0.025	0.027	0.002	0.003
Specificity	0.986	0.986	0.986	0.985	0.986
Probability of Detection	0.022	0.015	0.014	0.01	0.01
Probability of False Detection	0.065	0.008	0.007	0.057	0.05
Rank	4	1	2	5	3

Large numbers are noted for “Positive (P) – Negative (E)” values in the contingency matrices for all the stations. This is mainly due to more number of observations were identified as anomalies or outliers by the tool than the expert. The number of anomalies identified tool are influenced by: 1) rate of change threshold parameter and 2) constant data anomalies. The former is site-specific and the latter depends on the threshold time interval that is used in the tool. Exhaustive analysis of several sites along with diagnostics of HDET tool results need to be conducted to identify any issues with the methods and also to obtain reasonable values for these parameters.

Large numbers are noted for “Negative (P) – Positive (E)” values in the contingency matrices for two stations. This indicates that HDET was not able to identify the outliers/anomalies but the expert has flagged several observations as anomalies. This is mainly due to situations where observations are flagged by the expert when he/she made minor modifications (a very small change in the numerical value) to the data values. All stations have several constant data anomalies that were identified by HDET and not by expert. While this is beneficial for further evaluation of the data, it is essential to know why these data were not flagged by the expert. Domain knowledge of the expert(s) need to be understood and expressed as rules to improve HDET. The stations (or sites) evaluated by HDET have very few outliers/anomalies. Observations at different sites (other than the six used currently in this phases of the study) with wide range of anomalies identified by the expert are ideal for robust testing of the tool.

Information Transfer Program Introduction

Through the Information Transfer Program the Florida WRRC actively supports the transfer of results of water resources research in Florida to the scientific and technical community who are actively addressing Florida's water resources issues.

Florida Water Resources Information Transfer

Basic Information

Title:	Florida Water Resources Information Transfer
Project Number:	2014FL316B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	3
Research Category:	Not Applicable
Focus Category:	None, None, None
Descriptors:	None
Principal Investigators:	Kirk Hatfield, Mark Newman

Publications

1. Annable, M.D., M.C. Brooks, J.W. Jawitz, K. Hatfield, P.S.C Rao, and A.L. Wood. (2014). Flux-based site assessment and management, Chlorinated Solvent Source Zone Remediation, Edited by B.H. Kueper, H.F. Stroo, C.M. Vogel, and C.H. Ward. ISBN:978-1-4614-6921-6(H); 978-1-4614-6922-3(P), Springer, pp 187-218.
2. Perminova, I.V., S. N. Kalmykov, N. S. Shcherbina, S. A. Ponomarenko, V. A. Kholodov, A. P. Novikov, R. G. Haire, K. Hatfield. 2014. Humic functional derivatives and nanocoatings for remediation of actinide contaminated environments, Nanomaterials for Environmental Protection, Edited by B. I. Kharisov, O. V. Kharissova, and H. V. R. Dias. ISBN: 978-1-118-49697-8 Copyright © 2000 Wiley, Inc., pp 483-503.
3. Klammler, H., K. Hatfield, M.M. Mohamed, I.V. Perminova, M. Perlmutter. 2014. Capture and release zones of permeable reactive barriers under the influence of advective-dispersive transport in the aquifer, Advances in Water Resources. 69, 79-94.
4. Klammler, H., B. Nemer, and K. Hatfield, 2014. Effect of Injection Screen Slot Geometry on Hydraulic Conductivity Tests, Journal of Hydrology, VOL. 511, 190-198.
5. Shcherbina, N.S., S.S. Kalmykov, L.A. Karpiouk, S.A. Ponomarenko, K. Hatfield, R. Haire, I.V. Perminova. 2014. Non-reversible immobilization of water-borne plutonium onto self-assembled adlayers of silanized humic materials, Environmental Science & Technologies, http://dx.doi.org/10.1021/es404583f.

Information Transfer Program FY 2014

During the review period, the Florida WRRC actively supported the transfer of water resources research findings and results to the scientific and technical community that addresses Florida's water resource problems. The Center provided support for preparation and presentation of **19 peer-reviewed journal articles, 2 book chapters, 7 proceedings and presentations, 3 Ph.D. Dissertations, 2 Master's Thesis, and 1 US Patent.**

WRRC Website: The Center maintains a website (http://wrrc.essie.ufl.edu/) which is used to provide timely information regarding applied water resources research within the state of Florida. The Center website provides information regarding ongoing research supported by the WRRC, lists research reports and publications that are available, and provides links to other water-resources organizations and agencies, including the five water management districts in Florida and the USGS.

WRRC Digital Library: The Center maintains a library of technical reports that have been published as a result of past research efforts (Dating back to 1966). Several of these publications are widely used resources for water policy and applied water resources research in the state of Florida and are frequently requested by others within the United States. As part of the WRRC information and technology transfer mission, the library was converted to digital form and is maintained free to the public through the WRRC Digital Library which is housed on the center website http://wrrc.essie.ufl.edu/reports/.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	2	0	0	0	2
Masters	3	0	0	0	3
Ph.D.	6	0	0	2	8
Post-Doc.	1	0	0	0	1
Total	12	0	0	2	14

Notable Awards and Achievements

The WRRC continues efforts to maximize the level graduate student funding available to the state of Florida under the provisions of section 104 of the Water Resources Research Act. Listed below are some of the Center s notable achievements for FY 2014:

STEM Education: Recognizing the importance of STEM (Science, Technology, Engineering, and Mathematics) Education initiatives, the Florida Water Resources Research Center is proud to have supported the research efforts of 8 Ph.D., 3 Master's, and 2 Bachelor's students along with one Post-Doctoral researcher all focusing on water resources issues during Fiscal Year 2014.

UCOWR Best Dissertation Award: Dr. Ken Friedman s dissertation, Simulation/Optimization of Alternative Water Supply Planning Using Parcel Level Demand Estimation and Management Strategies was selected as the first place recipient of the 2015 UCOWR Ph.D. Dissertation Award in the category of Water Policy and Socio-Economics. Dr. Friedman s work was supported in part by WRRC project 2011FL269B. Dr. Friedman presented his research at the UCOWR/NIWR/CUAHSI Conference, Water is Not for Gambling: Utilizing Science to Reduce Uncertainty, June 16-18, 2015 in Las Vegas, Nevada.

US Patent Awarded (US61/969,382): Sediment Bed Passive Flux Meter, 2015. This student-lead seed project (2013FL311B) generated a patent for a new passive technology capable of measuring water and contaminant fluxes across sediment beds in streams, rivers, lakes, and estuaries. The resulting technology has a wide range of potential applications.